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BEARING OF FORESTS ON THE THEORY OF CONTINENTAL DRIFT

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FORESTS or continents—which of these have moved over the surface of the earth during the past? This question arises when we consider the fossil forests of the north, where long winters with sub-zero temperatures make it impossible for trees to live to-day. It again comes to mind when we uncover in the rocks of the western United States petrified logs and leaf impressions of trees which now exist only in the tropics. Such records of past life establish the fact of great changes during earth history. But whether these changes have involved migrations of forests southward or movements of whole continents northward is a question on which paleobotanists and geophysicists are not always in agreement.

On first thought it seems more probable that the forests have moved rather than the continents. The span of a human life is too short to witness major changes, but we instinctively feel, as implied by such expressions as "solid ground" and "everlasting hills," that the continents on which we live are the epitome of permanence. Many of us have witnessed changes in forest distribution, largely, it is admitted, through man's clearing of woodlands for other uses. Such superficial observations and reactions can scarcely be weighed seriously in a question involving world-wide changes during scores of millions of years. It is necessary to turn to the fossil record for the solution of a problem which had its beginning long ages before man came to live upon the earth.

The hypothesis of continental drift, as presented by Wegener, assumes the original massing of the existing land masses into an aggregate termed Pangaea. Subsequently the American continents are thought to have broken off and drifted to their present position. As Wegener states in his book, "The Origin of Continents and Ocean Basins," the starting point of this idea of continental union and dispersal was the close correspondence of the coasts of Africa and South America. This suggested that they had once been joined and that they subsequently drifted to opposite sides of the Atlantic Ocean. Evidence was also presented for the fusion of North America with Europe. Wegener concluded that as recently as the geologic period preceding our own, there was only a narrow inland sea separating these continents, and that the Atlantic Ocean as we now know it did not come into existence until the period in which we live. Although his discussion of north-south movements involves some contradictions, Wegener definitely indicates his belief that the position of the continents with relation to the north pole has also changed widely in later

geologic time. Writing more recently, duToit makes the following statements in his book, "Our Wandering Continents": "From the Cretaceous onwards we can accept a series of polar 'shifts,' . . . A general movement at first north, then north-east, thereafter north again and finally east, modified to some extent by the continued *divergence of the two continents*"; and "Indeed, from the mid-Palaeozoic onwards the lands must have crept *northwards* for thousands of kilometres to account for their deduced climatic vicissitudes. *Such, indeed, constitutes the most telling demonstration of the reality of Continental Drift.*"

The paleobotanist approaches the question of continental drift versus forest migration with an attitude which has been current among students of the earth sciences since Hutton and Lyell, over a century ago, put forth the doctrine that the present is the key to the past. Viewing the vegetation of to-day from the pole southward, we note gradual changes from boreal to temperate and from temperate to tropical forests. Dwarfed spruce, willow and birch on the Alaska tundra give way to maple, elm or redwood at middle latitudes, and these in turn disappear as fig, laurel and palm attain dominance in Central America. This change in modern forests southward we interpret as largely a response to rising temperatures. Figs may not live near the arctic circle because of the severe winters; the trees of the north can not meet competition with forest giants in the tropics. The result is a zoning of vegetation which enables a student of modern plants to estimate the approximate latitude and temperature of his position from the character of the forest. Similar zoning characterizes the forests of Eurasia as well. This must of necessity be the case if temperature is the primary factor in plant distribution, since —with certain modifications to be discussed later—temperature is a function of latitude. Fig. 1 shows the distribution of several of the major floristic units in the northern hemisphere, together with the isotherms for the winter season. This is the season most significant to our dis-

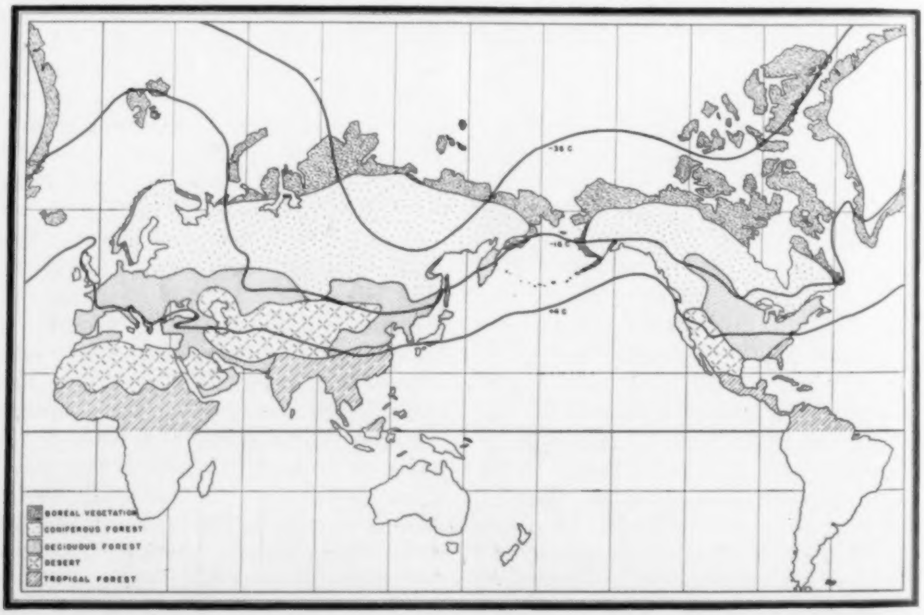


FIG. 1. DISTRIBUTION OF JANUARY ISOTHERMS AND VEGETATION IN THE NORTHERN HEMISPHERE.

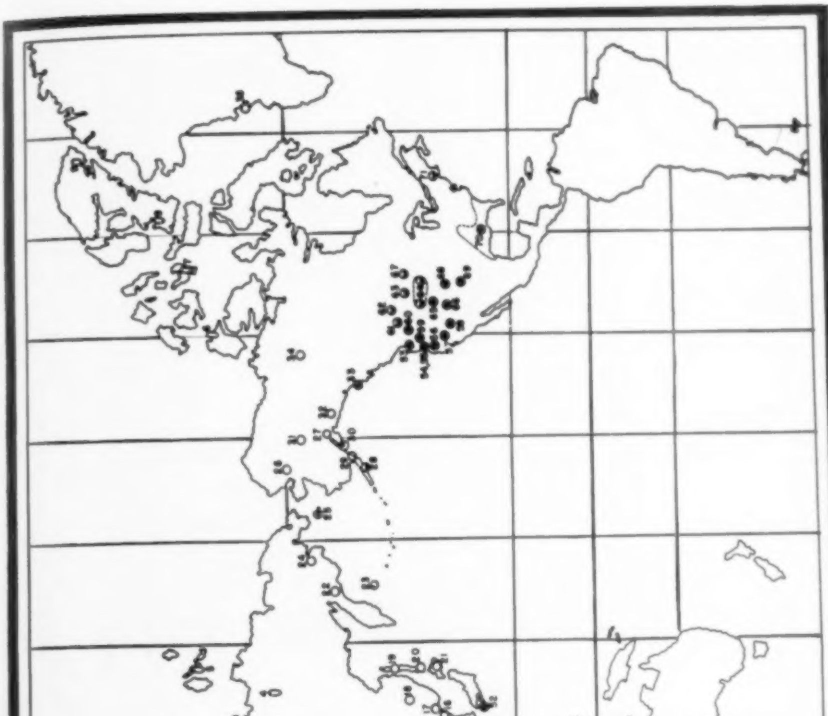


FIG. 2. DISTRIBUTION OF OLDER TERTIARY FLORAS IN THE NORTHERN HEMISPHERE.

FIG. 4. FOSSIL LEAVES OF MAGNOLIA
FROM THE EOCENE FOUND IN OREGON (LATITUDE 44° NORTH). REDUCED ONE THIRD.

FIG. 3. RAINFOREST OF GUATEMALA
(LATITUDE 16° NORTH.) SIMILAR TO SUBTROPICAL EOCENE FLORAS OF MIDDLE LATITUDES.

cussion, since minimum temperatures largely determine the northward limits of forest distribution.

The paleobotanist finds evidence that forest zoning can be traced back for tens of millions of years, to the epoch known as the Eocene. There are abundant fossil records of Eocene plants in the northern continents which make possible the reconstruction of a zone of subtropical forests, as indicated by the black circles in Fig. 2. At each of the localities so marked, there have been found leaves, fruits or stems of plants which resemble those now living in the tropics or on their borders. Some of the more common of these plants are the avocado (*Persea*), chumico (*Tetracera*), fig (*Ficus*), magnolia (*Magnolia*) and nipa palm (*Nipadites*). Their fossil leaves are relatively large and thick, like those of modern plants which live in warm regions. A slab of fossils and the modern forest containing similar living trees are pictured in Figs. 3 and 4. Our conclusion that such fossil floras indicate subtropical temperatures is based upon the assumption that plants of the past had essentially the same habitat requirements as their nearest living relatives. Single species taken by themselves would not justify such an assumption, but when most or all of the members of a fossil forest indicate warm living conditions, we may conclude with confidence that this forest lived south of the zone of winter frosts.

On our map several circles along the northern fringe of the Eocene subtropical zone are white in their northern halves. This indicates that the fossil floras which they represent were transitional in composition between subtropical and temperate forests. The latter, shown by white circles, occupied a latitude averaging 55 degrees, and were made up largely of plants which live to-day in regions where the temperature is intermediate between tropical and boreal. Some of the more common members of this temperate flora are basswood (*Tilia*), chestnut (*Castanea*), elm (*Ulmus*), hornbeam (*Carpinus*), maple (*Acer*), oak (*Quercus*), redwood (*Sequoia*), sycamore (*Platanus*) and walnut (*Juglans*). Fossil remains of these trees are found widely in Eocene deposits of Alaska, Greeland, Spitzbergen and northeastern Asia. A slab of redwood twigs is shown in Fig. 6, and adjacent to it a picture of the coast redwood forest of California.

Still farther north, where trees are now stunted or wholly absent, there are several localities where the vegetation of the Eocene was limited almost entirely to boreal plants such as birch (*Betula*), poplar (*Populus*), spruce (*Picea*) and willow (*Salix*). These are indicated by ovals on our map, and are not so numerous as in the other zones due to inadequate information regarding fossil plants in extreme high latitudes. Eocene leaves of spruce and alder from Grinnell Land are shown in Fig. 7, and Fig. 8 shows the modern Alaska habitat of similar plants. The zonation of these northern floras and of those farther south is closely similar to that of corresponding modern forests. Vegetation of a given climatic type is at approximately the same distance from the north pole in Eurasia as in North America, from which we conclude that these continents were grouped about the north pole in essentially their present position as far back as Eocene time.

A striking difference between the Eocene distribution of these floras and their present occurrence is that in every case they ranged farther north in the past. The subtropical forests, now located within 36 degrees of the equator, ranged beyond 51 degrees north latitude; the temperate forest lay 20 degrees north of the center of its modern range; and the boreal forest, extending into regions where trees no longer can live, had outposts 20 degrees north of

FIG. 5. CALIFORNIA REDWOODS
SIMILAR TO THOSE THAT GREW AS FAR NORTH AS THE ARCTIC CIRCLE IN THE EOCENE AGE.

FIG. 6. FOSSIL REDWOOD LEAVES
FROM EOCENE DEPOSITS OF ST. LAWRENCE ISLAND, ALASKA, LESS THAN 200 MILES FROM THE ARCTIC CIRCLE.

the latitude in which it is best developed at the present time. The subsequent migration of these forests southward to their present positions we interpret as due to climatic change,—a gradual lowering of temperature which made it impossible for them to survive in the north. Supporting this idea of a climate becoming colder during later geologic time is the evidence of fossil shells; marine molluscs of types now characterizing warm seas ranged as far north as Alaska as shown by their occurrence there in rocks of Eocene age. Mammals to-day limited to the warmer parts of the world also lived well to the north of their present homes. It is not within the province of this paper to consider the causes of such reduction in temperature, but the fact of its change seems to be well established by the fossil record of organisms which lived both on the land and in the sea. The resulting shift of forests southward for equal distances in North America and Eurasia (see Figs. 2 and 1) indicates that as far back as Eocene time these continents were grouped around the north pole in their present relative positions. The latter point is worthy of emphasis, since the consensus of opinion among exponents of continental drift places the pole at approximately 45 degrees north latitude and 170 degrees west longitude during the Eocene. By this they do not necessarily mean that the position of the axis of rotation has been altered, but rather that the continents had a different relative position around the poles; on Wegener's map North America was turned so that the present Pacific Coast faced northward instead of westward; Europe lay off to the south, with Spitzbergen at latitude 40 degrees and Greenland at about 30 degrees. The walnuts, oaks and redwoods which make up so large a part of the fossil flora from these localities now live in comparable latitudes, and a hypothesis which has moved them northward thus meets the known facts of forest distribution during the Eocene. The subtropical floras farther south in England and France contain figs and magnolias equally well suited to the latitude 65 or 70 degrees south of the pole, as based on this concept of continental drift.

But when we come to the western hemisphere and examine the position of the corresponding North American forests, strange inconsistencies are at once apparent. The Eocene flora of Alaska would have lived only 15 degrees away from the north pole, at a latitude much too high for temperate forests if the climate as postulated was like that of to-day; the subtropical flora of Oregon would have lived about 30 degrees south of the pole, at a latitude now too severe for the best development even of a temperate flora. It is apparent that in settling the problems

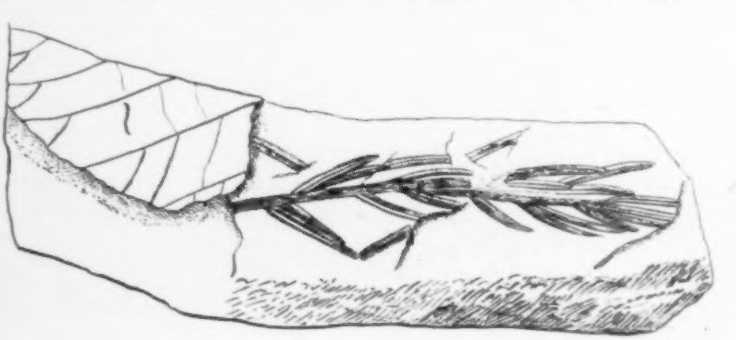


FIG. 7. FOSSIL LEAVES OF SPRUCE AND BIRCH FROM THE EOCENE OF GRINNELL LAND.

FIG. 8. MODERN TUNDRA VEGETATION OF ALASKA (LATITUDE 65° NORTH)
WITH TREES AND SHRUBS SIMILAR TO THOSE OF THE BOREAL EOCENE FLORAS.

of fossil floras on their own continent, European exponents of the theory of continental drift have condemned our American forests to retroactive frost and freezing. The character and distribution of Eocene forests in North America definitely refutes the suggestion that the northern continents have changed their positions around the pole during later geologic time. They lay in essentially the same latitudes as floras in Eurasia which contain similar or identical fossil species, and were distributed in zones governed as they now are by their distance from the existing north pole. Any explanation of changed climatic distribution since the Eocene must apply to all the continents of the northern hemisphere, rather than to a particular area selected because it seems best to fit a hypothesis.

There is an equally fundamental objection to the map of the Eocene continents as postulated in Wegener's Pangaea. As indicated above, there was no Atlantic Ocean separating North America from Europe during that epoch. In the absence of an ocean, no current like our modern Gulf Stream could have carried warm waters to the shores of Scandinavia as it does to-day. The effects of the Gulf Stream upon living forests in northwestern Europe may be seen by reference to Fig. 1. Trees which are characteristic of central Europe range northward beyond the Arctic Circle along a shore to which are brought the warm waters from the Gulf of Mexico. The northward turning of isotherms in this region is an expression of the milder air temperatures which result from this current. In the Pacific Ocean there is likewise a response to the warmer climate resulting from the Japan current, for temperate forests extend farther north along the coast of Alaska than in the interior. These relations of ocean currents to land temperatures may be summarized by stating that shores are warmer than continental interiors, especially on the windward sides of the continents and in winter. At this season isotherms turn northward over the oceans, southward over the continents, in the northern hemisphere.

It is obviously impossible to draw isotherms based on direct observation of Eocene temperatures, for weather bureaus were not functioning sixty million years ago, nor were there ships at sea to radio information regarding the oceans. But by drawing lines known as isoflors we may approximate the positions of Eocene isotherms. These lines connect floras of the same general composition, which are assumed to indicate, as do similar floras to-day, essentially the same climatic background. The isoflor connecting the localities where subtropical floras have been recorded, as shown by Fig. 9, swings up the west coast of Europe into England, then turns southward into France and trends in a southeasterly direction, with a bulge north over the Black Sea, across Eurasia to the coast of central China. Here it turns northward along the coast of Japan, reaching the coast of western America in Washington and Oregon, swinging southeastward to Tennessee, and thence north across the Atlantic to the British Isles. The Eocene isoflor connecting temperate floras likewise swings far to the north on the western coast of Europe to Spitzbergen, thence southward across Russia to Korea and southern Siberia, turning northward around the shore of the Pacific to Alaska, trending southeasterly across Canada, and northward again in the Atlantic on both sides of Greenland. Fewer fossil localities are available for the boreal isoflor, but it also swings northward over oceans and southward across continents. So closely do the Eocene isoflors correspond in position to the modern winter isotherms of the

northern hemisphere that we may assume they have essentially the same significance as indicators of minimum temperatures. And since they swing northward over the oceans as now constituted, southward over the continents as we know them to-day, we are forced to the conclusion that these ocean basins and continental platforms must have stood in essentially their present positions as far back as Eocene time. Again there is direct contradiction of the hypothesis that the northern continents have moved since the Eocene, and that the Atlantic basin has resulted from the gap formed by the cleavage of the New World from the Old. There must have been an Atlantic Ocean between North America and Europe at the time our fossil forests were living, else why should we have evidence of an Eocene equivalent of the Gulf Stream in the northward turning of the isoflors between Greenland and Scandinavia? Plotting the Eocene fossil plant localities on Wegener's Pangaea, the isoflors would have run in a nearly north-south direction rather than in parallel lines around the poles as do isotherms to-day, and as isotherms must always have run if heat from the sun has been the controlling factor in earth temperatures and plant distribution.

We conclude that the evidence of Eocene floras, made up of close relatives of living trees whose climatic requirements are well known, strongly refutes the hypothesis of continental drift during later geologic time. The question of drift at an earlier date in earth history must be answered by reference to the nature and distribution of plant fossils in older rocks, and need not be considered here. But for tens of millions of years, since life on the earth has been similar to that of to-day, North America and Eurasia have occupied their present position with relation to the north pole and the ocean basins. During this latest chapter of life history, forests have migrated southward in response to changing climate, over conti-

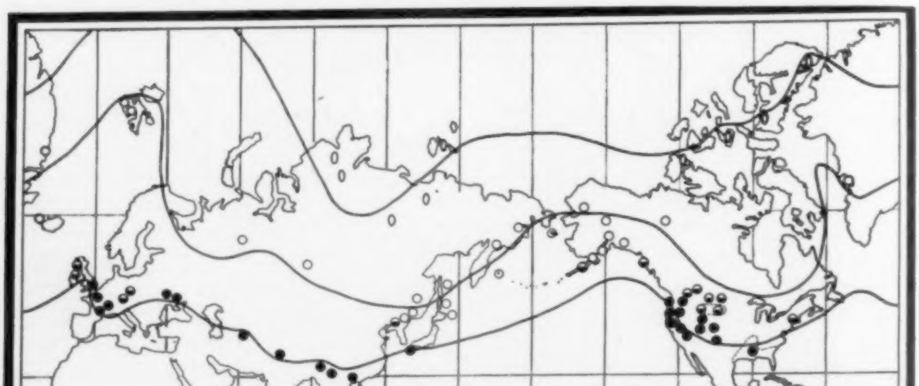


FIG. 9. DISTRIBUTION OF EOCENE ISOFLORS IN THE NORTHERN HEMISPHERE.

nents whose stability through the ages seems well established.

List of Older Tertiary Localities or Formations
(Shown on Fig. 2)

Cool temperate

(1) Taimyr River, Siberia; (2) Boganida River, Siberia; (3) Tschirmyi, Siberia; (4) Tas-takh Lake, Siberia; (5) New Siberia Islands; (6) Banks Island; (7) Bathurst Island; (8) Ellesmere Island; (9) Grinnell Land.

Temperate

(10) Iceland; (11) Sabine Island, Greenland; (12) Spitzbergen; (13) Lozva River, Siberia; (14) Simonova, Siberia; (15) Fushun, Manchuria; (16) Kisshu-Meisen and Ryudu, Korea; (17) Possiet Bay, Siberia; (18) Khabarovsk, Siberia; (19) Dui, Sakhalin; (20) Naibuchi, Sakhalin; (21) Shitakara and Ishikari, Hokkaido, Japan; (22) Korf Gulf, Siberia; (23) Commander Islands; (24) Anadyr River, Siberia; (25) St. Lawrence Island; (26) Kobuk River, Alaska; (27) Eska Creek, Alaska; (28) Chignik, Alaska; (29) Cape Douglas, Alaska; (30) Port Graham, Alaska; (31) Central Yukon Valley, Alaska; (32) Berg Lake, Alaska; (33) Kupreanof Island, Alaska; (34) Great Bear River, MacKenzie; (35) Atanekerdluk, Disko Island, Greenland.

Subtropical

(36) Antrim County, Ireland; (37) Isle of Mull, Scotland; (38) London Clay, England; (39) Paris Basin, France; (40) Celas, France; (41) Sezanne, France; (42) Bavarian Alps; (43) Jesuitengraben, Bohemia; (44) Kiev, Ukraine; (45) Elisabethgrad, Ukraine; (46) Eroilan-duz, Turkestan; (47) Kasauli, India; (48) Deccan Plateau, India; (49) Assam, India; (50) Burma, Further India; (51) Na-giao, Indo-China; (52) Takashima, Kyushu, Japan; (53) Steel's Crossing, Washington; (54) Comstock, Oregon; (55) Goshen, Oregon; (56) Ashland, Oregon; (57) Weaverville, California; (58) Chalk Bluffs, California; (59) Clarno, John Day Basin, Oregon; (60) Swauk, Washington; (61) Calgary, Alberta; (62) Red Deer River, Alberta; (63) Upper Ravenscrag, Saskatchewan; (64) Fort Union, from Yellowstone Park to South Dakota; (65) Wind River, Wyoming; (66) Green River, Wyoming; (67) Roche Percee, Saskatchewan; (68) Denver Beds, Colorado; (69) Raton, Colorado and New Mexico; (70) Wilcox, Claiborne and Jackson, southeastern United States; (71) Brandon, Vermont.

STUDENT TRAINING AND NATIONAL DEFENSE

I agree with what I understand to be the view of the Army and Navy, that military training is best conducted by the Army and Navy in their own establishments. The university may train people in highly specialized work for which the Army and Navy have no facilities or personnel. It may offer incidental opportunities to its students to gain some elementary military knowledge, provided such activities do not interfere with their education. Beyond these kinds of effort the colleges and universities should leave military training to the military forces and devote themselves to giving their students, while they have them, the best education they can. Military training and education, at the university level, do not mix. The Army and Navy are much better qualified to give military training than the universities, the universities are much better qualified to give education than the Army and Navy. We shall get the best results if each group confines itself to the field of its special competence.

I also agree with the views expressed by Mr. Roosevelt, who has said, "Young people should be advised that it is their patriotic duty to continue the normal course of their education unless and until they are called, so that they will be well prepared for greatest usefulness to their country. They will be promptly notified if they are needed for another patriotic service." I go so far as to favor the prohibition of volunteering, on the ground that it interferes with a program of putting the right man in the right place and permits hysteria and social pressure to determine the course of many young people.

On the other hand, I do not favor any exemptions from the draft for college and university students as such. Each man called should be put at that work contributing to national defense for which he is best qualified. If he will be most useful to his country receiving specialized training at a university, he may be assigned to work there, or his military service may be deferred until his training is completed. But nothing would be worse for higher education in this country than to have it thought that enrolment in a college or university is a method of avoiding conscription.—*Report of Dr. Robert M. Hutchins, president of the University of Chicago, to alumni and friends of the university.*

SOME ASPECTS OF CENTRAL AMERICAN BIRD-LIFE

II. PLUMAGE, REPRODUCTION AND SONG

By Dr. ALEXANDER F. SKUTCH

SAN JOSÉ, COSTA RICA

IV

Seasonal changes in the coloration of the same individual bird are a phenomenon in the bird-life of the North Temperate Zone so familiar that we are apt to look upon it as a characteristic of birds in general. I had already devoted some years to the study of Central American birds before it dawned upon me that I did not know one single instance of seasonal change in coloration among the resident species. Since then, keeping this problem especially before me during the course of seven years, I have convinced myself that a seasonal change of coloration does occur only in a single species of finch, the far-ranging blue-black grassquit (*Volatinia jacarini*). The plumage of the males among these little birds of grassy places, shining blue-black during most of the year, is clouded with brown during its closing months—yet even then a few individuals in full breeding plumage will be seen. I at one time considered these brownish males to be young individuals moulting into the adult plumage; but in certain districts, in December, they form far too great a proportion of the entire male population for this view to be tenable. Careful and continued watching of many species in the field has failed to bring to light another convincing example of seasonal change in attire among the inland birds of Central America, although a comparison of specimens collected at various seasons might reveal changes too slight to be noticed in the free, living birds.

The semi-annual change in array seems to be a phenomenon somehow linked with the habit of migration. Not that all migratory birds, even those brightly colored, exhibit it, or all non-migratory birds fail to manifest it—this is far from being true. Yet many facts, some of them concerning the most familiar birds, are so suggestive of a relationship—by no means a simple and direct one—between migration and seasonal plumage-change, that students of birds can not afford to disregard them. Is it merely a matter of chance that the brilliant red male cardinal, a non-migratory species, wears the same plumage amid winter's snow and summer's verdure, while the bright indigo bunting, cardinal's neighbor during the summer months, is far more plainly attired while in his winter home far away? The critical reader will object that the painted bunting, certainly no less splendid in his parti-colored array than his close relation, the indigo, is clad in the same colors the year around, in spite of his migrations. But the painted bunting performs shorter migrations; and some may linger over the winter in southern Florida: facts which suggest that the migratory urge is weaker in this species than in the indigo bunting. Turning to a different family, is it merely a matter of chance that the migratory summer tanager wears the same bright red plumage in his winter home in Central America and his summer home in southern United States; while the scarlet tanager, which performs a much longer annual journey, changes the intensely brilliant cloak of scarlet and black that

he wears in northern United States for a far less colorful dress during his sojourn in South America? Is it a purely fortuitous coincidence that the bobolink, the greatest traveler in the oriole family (Icteridæ), undergoes the most complete seasonal changes in coloration to be found in that great family, most of whose members are non-migratory? These examples and a number of others that might be cited suggest the possibility of a quantitative relationship between extent of migration and annual change in coloration; but at the same time their diverse character serves to warn the student that this problem is by no means a simple one, and that almost any generalization he may dare to arrive at must be followed by a list of exceptions.

The seasonal changes of coloration of migratory birds can not, in most cases, be explained by the necessity of diverse color-patterns to make the same individual inconspicuous in the different environments of its winter and summer homes. In the first place, birds as a rule seek the same type of habitat in their wintering as in their breeding range, those which live in the forest in the North seeking forest in the South, those which breed in grassland passing the winter in grassland, and those which prefer low, tangled thickets frequenting such vegetation the year about. The red summer tanager is neither more nor less conspicuous among the foliage of a Costa Rican forest composed of a hundred species of trees than in a northern forest of half a dozen kinds; and his enemies are no more numerous in his winter home. Secondly, diurnal, arboreal birds, in my experience, depend little if at all for their personal safety upon "protective coloration," their ability to escape detection; rather they stake their lives upon their alertness and fleetness. At the nest, on the contrary, the parent's ability to avoid detection may mean the difference between life and death, not for the mobile parent, but for the immobile occupants of the nest. How many a nest, which otherwise would most probably have been

VOLCÁN SANTA MARÍA (ABOUT 12,400 FEET)
PHOTOGRAPHED FROM THE PLATEAU NEAR QUEZALTENANGO, GUATEMALA

overlooked, has been revealed to me by the parent bird's abrupt departure!

Closely allied to the questions we have been discussing is that of the differences in coloration of the male and female of the same species. In eastern North America, so many of our brilliant male birds have soberly colored mates that we come to consider this as the natural order of things among feathered beings. But the situation is quite different in Central America. Among the highly migratory wood warblers of temperate North America, the male, if at all gaily attired, has a mate of duller plumage. But among the non-migratory warblers of Central America, many of which remain paired through the year, the sexes are alike in plumage more often than not. This is true of such typical genera as *Myioborus, Basileuterus* and *Ergaticus,* species of which are among the most beautifully attired of warblers. Again, among the highly migratory orioles (*Icterus*), a striking difference in coloration of male and female is the rule; but among the non-migratory Central American orioles, no less brilliant in their splendid array of gold and black than their migratory cousins, the sexes are alike or only slightly different in coloration. Among the Central American finches, it is noteworthy that none of the numerous species which I have listed as remaining mated through the year exhibits sexual differences in coloration; while those which aggregate into large flocks after the close of the nesting season (chiefly the seed-eaters, grassquits and goldfinches) show pronounced sexual differences in plumage. The same holds true of the tanagers. In the genera *Thraupis, Tangara, Calospiza* and *Calliste,* containing some of the most lovely and gem-like of Central American birds, those species best known to me commonly fly two by two at all seasons, except when accompanied by young dependent upon them for support; and male and female are exactly or essentially alike in plumage. On the other hand, in such genera of beautiful birds as *Euphonia, Chlorophonia* and *Ramphocelus,* which form conspicuous flocks (certain species of *Ramphocelus* being polygamous by excess of females), sexual differences in coloration are most conspicuous. Among the typical honeycreepers, *Cyanerpes* and *Dacnis* travel in flocks and the sexes are very different in appearance; *Cœreba* never flocks, possibly remains paired, and the sexes are identical.

Thus among migratory song-birds, the male, if brighter than his mate during the breeding season, frequently, but by no means invariably, assumes a plumage more like hers after its close. On the other hand, among the non-migratory song-birds of tropical America, especially those which live in pairs through the year, there is a strong tendency for the female to wear a dress quite as bright as the male's; and both retain their colorful attire at all seasons. If we seek a common causative agent which may unify things seemingly so diverse as migration, seasonal changes in plumage, sexual differences in plumage, and the habit of remaining paired through the year, it seems likely that this agent may be found in the internal secretions of the organs of reproduction. We know, on the one hand, that these exert a strong influence upon the migratory urge, and on the other, that they are responsible for the sexual differences in plumage.

Intimately linked with the subjects of sexual and seasonal diversities in plumage in the same species is that of the age at which the young bird acquires the coloration of the adult. Among the species of temperate North America which exhibit pronounced sexual, and frequently seasonal, differences in coloration, the young males as a rule pass their first winter in a dress closely similar to that of their

BIRDS OF LOWLAND RAIN-FOREST IN PANAMÁ
Left: FEMALE RED-HEADED MANAKIN (*Pipra mentalis*) ON NEST. *Right:* FEMALE SLATY ANT-SHRIKE (*Thamnophilus punctatus*) ON NEST.

mother, and acquire the bright nuptial dress at the outset of their first nesting season, by means of the prenuptial moult. But in many kinds of Central American birds, of which the sexes are alike, I have observed that the young, decidedly different from their parents at the time of quitting the nest, promptly change into the brighter plumage of the adults, by means of the postjuvenal moult. Without the retarding influence of winter, or of migration, the youngsters acquire the bright adult dress far earlier than their cousins of "temperate" regions. In quite a number of species of Central American finches, warblers, tanagers, mockingbirds, wrens, etc., a few months after the close of the breeding season, young and old, males and females, are alike, or at least confusingly similar, in appearance.

In the species of which male and female are distinct in plumage, the young males, at first resembling their mothers, may assume the colors of their fathers at their first (postjuvenal) moult. Or, less frequently, they may wear a dull or intermediate plumage for a year or more, even breeding in it, as occurs among Central American birds in the yellow-crowned euphonia, the Costa Rican chlorophonia, some of the more deeply colored thrushes of the genus *Turdus* and certain manakins. The situation is exactly paralleled in such northern birds as the orchard oriole and the purple finch.

V

It has long been known to students of birds that the nests of tropical species commonly contain fewer eggs than those of the most closely related kinds of higher latitudes. Of the thousand nests of hundreds of species of Central American birds into which I have peeped, not one has held more than five eggs, excepting only those of the anis, which build com-

SUBTROPICAL RAIN-FOREST IN COSTA RICA

HEADWATERS OF RÍO SARAPIQUÍ (5,600 FEET). IN THE HAUNTS OF THE BELL BIRD, QUETZAL, SOLITAIRE, TOUCANET AND BARBET.

munal nests that cradle the offspring of several closely coöperating pairs. Two is the number of eggs most commonly found in the nests of Central American birds, including a great number of finches, tanagers, honeycreepers, flycatchers, manakins, antbirds, hummingbirds, doves and others too numerous to mention. Sets of three are by no means rare, of four less common, and of five distinctly uncommon. I have found so many only rarely, in the nests of cactus wrens, swallows, a kingfisher and a few others. A single egg forms the full set in the nests of certain pigeons of the genus *Columba*.

The fact that a certain bird lays smaller sets of eggs than another is not proof that it raises fewer offspring during the course of a year; it may compensate its smaller sets by a greater number of broods. It is important to learn whether Central American birds actually produce fewer offspring than the feathered kind farther to the north, or whether a longer breeding season, made possible by a tropical climate, offsets the smaller size of individual broods.

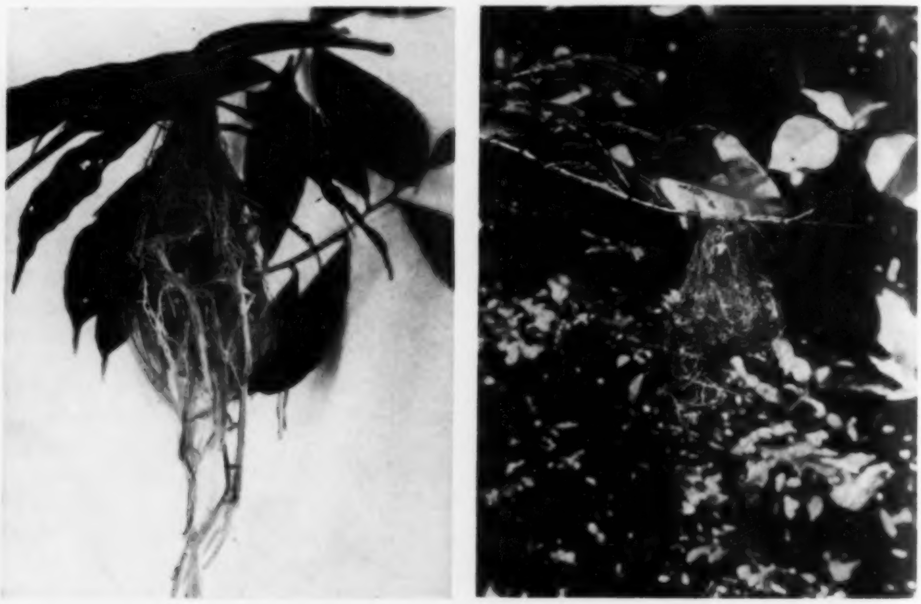
A few exceptional species, including Rieffer's hummingbird (*Amazilia tzacatl*), the ruddy ground dove (*Columbigallina rufipennis*) and the slaty antshrike (*Thamnophilus punctatus*), nest, in the Caribbean lowlands, *as species,* throughout the year. It is not known over how long a period the reproductive activities of a single individual may extend; but it is almost inconceivable that she should breed continuously. Each of these species lays regularly only two eggs in a set; of the three, the reproductive cycle of the antbird is slightly shorter than the others; if we set it at forty days, and assume that a pair breed continuously without a rest through the twelve months, they could raise at best nine broods, or eighteen fledglings, in the course of a year. Yet even admitting this highly improbable result, the antbirds could not equal the record of the English robin, which may lay eight eggs in a set, and is said to produce a maximum number of twenty in a single summer! The highest fecundity among Central American birds actually known to me by direct observation is that of a pair of house wrens (*Troglodytes musculus*), which between December and June laid four sets of four eggs each, in a gourd which I put up for them in southern Costa Rica, and successfully raised at least one fledgling in each brood.

There is good evidence from a number of sources that Central American birds lay fewer eggs in the course of a year than those farther to the north. Thus kingfishers raise only a single annual brood in Central America, as in temperate North America; but the tropical species lay sets only about half as large as those of the northern belted kingfisher. Many kinds of tropical birds which raise a single annual brood lay only two or three eggs in a set. Although, as we have seen, a few species breed throughout the year, and in the lowlands nests of one species or another are to be found in each of the twelve months, the breeding of the birds as a whole is a distinctly seasonal activity; and the great majority of them raise their families during the quarter-year between the vernal equinox and the June solstice. In the highlands, above five thousand feet, the concentration of nests within this period of three months is even more pronounced than in the lowlands. In the mountains of Guatemala, between eight and nine thousand feet above sea-level, I found that nearly all the birds (hummingbirds and honeycreepers excepted) nested in the brief period of most favorable weather between the last frost, at the beginning of April, and the advent of the rainy season in the middle of May. Most species raised only a single brood, no larger—sometimes

smaller—than that of the most closely related birds of the lowlands where the breeding season is longer, and notably smaller than the families of birds of higher latitudes.

But not only is the potential number of offspring, produced each year by a pair of Central American birds, small in comparison with that of northern species; the actual number of offspring is smaller still. In the high mountains of Guatemala, 55 per cent. of the nests which I had under observation produced at least one living fledgling; on a great banana plantation in the lowlands of the same country, 43 per cent. of my nests terminated happily; in a region of southern Costa Rica where somewhat less than half the forest remained standing, the percentage of successful nestings was reduced to 33; in heavy lowland forest in the Canal Zone, only 14 per cent. of my nests—one out of seven—escaped premature destruction. This astounding mortality of nests in the lowland forests I attribute chiefly to snakes; but there are many other predators. The big Swainson's toucans are insatiable nest-robbers; the graceful swallow-tailed kites pluck many an egg and nestling from exposed nests in the tree-tops; and I suspect that monkeys, violently swaying the boughs as they career wildly through the heights of the forest, must shake not a few eggs from frail and shallow nests such as are built by a number of the woodland birds—in addition to those devoured by the carnivorous Cebus or white-faced monkey.

Because of the tremendous loss of nests, I know few endeavors more discouraging than that of trying to obtain complete life-histories of the birds of the lowland forest. Happy the bird-watcher who can discover a pair of these forest-dwellers



NESTS OF CENTRAL AMERICAN FLYCATCHERS
Left: COZY NEST OF THE BENT-BILLED FLYCATCHER (*Oncostoma cinereigulare*). *Right:* RETORT-SHAPED NEST OF THE GRAY-HEADED FLYCATCHER (*Rhynchocyclus cinereiceps*). IT IS MADE OF FINE BLACK FIBERS AND ENTERED BY FLYING VERTICALLY UPWARD INTO THE END OF THE DOWNWARDLY POINTING TUBE AT THE LEFT.

CONTRASTS OF VEGETATION IN GUATEMALA

Left: CACTI AND THORNY SCRUB ON THE PLAINS OF ZACAPA (500 FEET). THE HOME OF THE MAGPIE-JAY, TURQUOISE-BROWED MOTMOT, WHITE-LORED GNATCATCHER AND LICHTENSTEIN'S ORIOLE

Right: FOREST OF CYPRESS WITH UNDERGROWTH OF BAMBOO (9,500 FEET). THE HAUNT OF THE GOLDEN-CROWNED KINGLET, BROWN CREEPER, MEXICAN TROGON, GUATEMALAN ANTPITTA AND GUAN.

who have come into a neighboring clearing to build their nest, for here their chances of success are somewhat greater—a fact of which the birds themselves seem to be aware.

Of late years, I have derived one most consoling thought from the many nests I have seen meet disaster. If the birds have such great difficulty in reproducing their kind, yet their number remains substantially constant from year to year, it follows that the adults must lead lives longer, and doubtless happier, than in regions where they succeed in raising large families, yet fail to become more numerous. My whole experience with Central American birds strengthens this deduction that their lives are, for birds, long and tranquil. Although I have upon countless occasions returned to a nest only to find that it had been emptied of its contents during the twenty-four hours since my previous visit, rarely indeed have I found evidence that either of the parents shared the unhappy fate of their offspring. In most cases where I devoted particular attention to the pair, I soon after found them hopefully preparing to nest once more. Although I have all too often had the disturbing experience of seeing a serpent devour nestlings or eggs, never once have I known a snake to catch an adult wild bird. Stories of snakes "charming" birds are admitted by most competent naturalists to be pure fable.

Central American hawks, although numerous in species, are for the most part rare in point of individuals. Many of these birds of prey seldom if ever devour smaller feathered creatures; and some, such as the guaco or laughing hawk (*Herpetotheres cachinnans*) are among

ALPINE MEADOW IN THE HIGHLANDS OF GUATEMALA

SCATTERED PINE TREES AND COPSES OF JUNIPER ON THE HIGH PLATEAU OF THE SIERRA CUCHUMATANES (10,600 FEET). HERE LIVE THE RAVEN, GUATEMALAN FLICKER, BLUE-CRESTED JAY, GUATEMALAN JUNCO, MEADOWLARK AND FLOWER-PIERCER

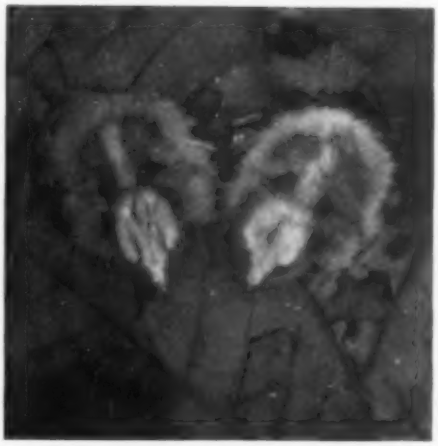
the very best friends the birds have, for they subsist almost entirely upon snakes, and so rid the smaller birds of the most relentless destructors of their nests. During the last six months, passed entirely in the field of southern Costa Rica, I have seen just one bird fall prey to a hawk: a swallow snatched in the fading light of evening from a vast migratory cloud of its kind. This single capture of a small bird by a hawk in the course of half a year about represents the average of my experience over a decade. The Central American hawk, apparently most destructive of bird-life, is one of the smallest, the swift, fierce-hearted, little white-throated bat falcon (*Falco albigularis*), which I have known on reliable evidence to carry off a blue-throated toucanet almost as big as itself, and which captures many smaller birds as well as large insects—but I have never known it to eat one of the bats for which it is named.

Bird-protection in the Central American countries is indeed in a lamentable state of neglect; and in the more populated districts, what with bird-trappers, small boys with sling-shots and larger ones with firearms, the feathered folk lead a precarious existence. But it should be remembered that the great Central American isthmus is chiefly wild, sparsely inhabited territory; it is in such country that I have preferred to live, and of such that I write. Here, with an abundance of food the year about; with a temperature never long below the freezing point, even on the highest peaks; with few feathered enemies, and their swiftness and alertness to prevent their falling into the clutches of other sorts; with perfect familiarity with the territory in which they reside the year round, and with its dangers; the tropical birds, having attained maturity, live far more securely than those of lands nearer the poles, and need produce fewer offspring each year

in order to maintain their population at its normal level.

The conditions of life of birds of higher latitudes are quite distinct. Each year they are faced with two alternative courses of action, both fraught with immense danger: they must either remain in the north during the cold months, or migrate southward. If they follow the former course, they may succumb to the combined effects of low temperature and insufficient nourishment; and many fall victims to predators whose hunger is sharpened by scarcity of food. The dangers which beset migrating birds, the storms which sometimes destroy them in vast numbers, the perils of a too early return in spring, the risk of impinging fatally upon some high obstruction while flying blindly through the darkness, are too well known to need description here. But one point in which migrating birds are at a disadvantage, as compared with the birds resident in the region through which the former are passing, has never, to my knowledge, been adequately stressed: The resident knows every source of danger peculiar to its district, and is perfectly familiar with the covers that afford the best security; the transient wanderer is unfamiliar with local conditions, and therefore more likely to meet disaster. It is easy to understand the urgent necessity of birds of the far north to raise large families during the brief summer months, to repair the losses their kind has suffered during the past winter.

Finally, the resident birds of Central America have time to build nests of a size, complexity and degree of comfort such as no migratory bird of high latitudes could afford to undertake. Many tropical birds are content with simple, easily constructed nests; simplicity of design seems to be the rule of architecture among finches, tanagers, antbirds and manakins. But other kinds, less readily satisfied, construct large or complex edifices for the accommodation of their young. One thinks of the great, elaborately designed and furnished castles of sticks built by the little spine-tails (*Synallaxis*) no bigger than wrens; of the commodious, often memorably beautiful pendent nests made by some of the tropical flycatchers, a family second to none in the diversity and complexity of its architecture; of the



WIDE-RANGING BIRDS

OF THE TROPICAL AMERICAN LOWLANDS. *Upper:* FLEDGLING RINGED KINGFISHER (*Megaceryle torquata*) *Lower:* NEWLY HATCHED CUYÉOS OR PARAQUES (*Nyctidromus albicollis*), RELATIVES OF THE WHIP-POOR-WILL AND THE NIGHTHAWK

long, swinging pouches skilfully and laboriously woven of fibrous materials by oropéndolas, caciques and many of the orioles. Nothing at all comparable to these various complex structures is to be found among the unsettled avian population of eastern North America; these birds could ill afford to devote a month to completing their nests, as tropical birds not infrequently do. In Argentina, in the South Temperate Zone, we do indeed find nests of great size and complexity, built by members of the ovenbird family (spine-tails and their relatives) and well described in W. H. Hudson's "Birds of La Plata." But these spine-tails are, I believe, resident where they breed; and Hudson states that some of them devote the winter to erecting, in a leisurely fashion, their impressive castles of sticks.

VI

One difference which certain people profess to find between tropical birds and those of northern lands is that the former are deficient in song. I here denounce, as the grossest and most libelous calumny, statements to this effect which for centuries have appeared in the writings of northern authors. Woodpeckers, kingfishers, hawks and owls do not produce lilting melodies in Canada or in Europe, why should the tropical representatives of these families be expected to do so? These and other groups of birds whose vocal organs are too poorly developed for song—toucans, parrots, motmots, barbets and a host of others—are so much more abundant in tropical than in temperate regions that they are likely to be considered, by superficial observers, as the typically "tropical" birds—whence follows the false conclusion that the bright birds of low latitudes are incapable of song. In justice to these songless groups of birds, it should be borne in mind that

RUFOUS-BREASTED SPINETAIL (*SYNALLAXIS ERYTHROTHORAX*)
ABOUT TO ENTER ITS CASTLE OF STICKS. THE BIRD IS SEEN IN THE RIGHT CENTER OF THE PHOTOGRAPH; THE DOORWAY IS THE ROUND OPENING IN FRONT OF ITS BILL

a number of them, including certain tinamous, trogons, motmots, antbirds and cotingas, utter notes of great, sometimes exquisite, beauty, although their vocal organs lack sufficient range and flexibility for the creation of complex song.

The true song-birds (oscines), although they form a relatively less important constituent among the teeming bird population of tropical lands than in the less varied avifauna of temperate countries, are represented in Central America by a larger number of species than is to be found in the vastly greater area of temperate North America. Thus one of the smaller Central American countries, Costa Rica, with an area of only 18,000 square miles, is the home of forty-three resident species of finches, twenty-two species of wrens, twelve species of thrushes, four kinds of orioles of the genus *Icterus*. One need only come to Central America with senses alert and mind free from prejudice to be convinced that, taken all in all, its birds are at least not inferior as songsters to the northern representatives of the same families.

But it is necessary to time one's visit at the proper season. A few kinds of birds, notable among them the wrens, sing more or less in all months; but the great majority are most tuneful during the breeding season, that quarter of the year occupied by the sun's northward swing from the Equator to the Tropic of Cancer. Some of the finest songsters, including the thrushes of the genus *Turdus*, are songful exclusively during their breeding season. A traveler arriving in Central America in December, at the beginning of the dry season—when the sky is full of sunshine and the meadows and clearings of bright blossoms, when nature is in general in her most attractive mood, but when scarcely any bird sings—might easily conclude that tropical birds are deficient in song. No doubt the prevailing silence of the birds, at certain seasons when earth and air and sky seem most to invite song, has been responsible, no less than the great abundance of species belonging to the songless "lower" families, for the growth of the old error that a parsimonious nature, having richly endowed tropical birds with color, withheld from them the gift of melody. It is as though a stranger, arriving in Costa Rica for the first time now in June, when two months of rain, following a severe dry season, have covered hill and vale with exuberant verdure, but when blossoming is near its lowest ebb, should conclude that this land of a thousand kinds of orchids is deficient in bright flowers!

THE TRAGEDY OF RUDOLF DIESEL

By Dr. HENRY CREW

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ONE of the outstanding biographies of recent times is the story which Eugen Diesel, a contemporary German writer of rare skill, tells of his father, the inventor of the engine. It appeared in Germany last year.

Hundreds of passengers on the Capitol Limited, within the last few years, have enjoyed its complete freedom from smoke and cinders; and many of these travelers have been surprised to learn that the engine furnishing power to the train never stops between Chicago and Washington. The locomotive comes to rest at several points; and the current which actuates the electric motor geared to the driving wheels is, of course, cut off as the train approaches each stopping point; but the "Diesel" maintains its customary speed with a continuity which reminds one of the gentleman in New York who purchased a ticket for Princeton and then stepped aboard a Pennsylvania train. Some forty minutes later, he sat looking out his car window and saw the sign "Princeton Junction" pass by at the rate of 70 miles an hour. Hurriedly calling the porter, he asked "Doesn't this train stop at Princeton Junction?" to which the reply was "No, sah! No, sah! This train does not even hesitate at Princeton Junction."

These non-hesitating "Diesels," as used on the Union Pacific streamliners and on the "400" between Minneapolis and Chicago, are now so familiar to travelers and the personality of the inventor is so little known that it may be worth while here to sketch the essential facts in the life and character of Rudolf Diesel, as set forth in his son's volume, "Diesel, der Mensch, das Werk, das Shicksal" (pp. 491, Hanseatische Verlagsanstalt, 1939). For, in spite of the vast literature which has already appeared dealing with heavy-duty, high-speed, marine and other types of the Diesel motor, little has been written in English about the man himself.

ANCESTRY

Rudolf Diesel came from a long line of Bavarian Protestants. During the four or five preceding generations, his ancestors were craftsmen and tradesmen, mostly bookbinders, paper-makers and manufacturers of leather goods. They cherished independence and were not afraid of work. In fact, they leave little doubt that the work and character of this remarkable inventor are the result of a long line of well-chosen progenitors and of good home training.

The grandfather, Johann Christoph Diesel—fourth of that name—was born at Memmingen, a town in Bavaria, some 60 miles west of Munich. He later settled in the neighboring city of Augsburg and married in 1828. The father, Gottlieb Theodor Hermann Diesel, was born here in Augsburg on 12 June, 1830. This, it will be observed, was a time when the peaceful quiet of German towns and cities was beginning to be disturbed by the political and social consequences of the French Revolution; also by that significant event known as the industrial revolution in England, with its mechanical and economic consequences. In fact, the continent was already beginning to think in terms of steam-engines, locomotives and power looms. The handworker was already finding himself either absorbed or displaced by the machine.

A few years later, during the tempest known as the revolution of '48, Theodor

Diesel, the father of our subject, became tired of his work as a bookbinder in Augsburg and set out on a journeyman's trip which landed him in Paris in 1850. Here he soon found employment in a shop were pocketbooks, purses and other articles were manufactured from Morocco leather.

Now it happened that about the time when Theodor Diesel left Augsburg and settled in Paris a young *Fräulein* of 23 years — Elise Strobel—left Nürnberg and went to London, where she performed the duties of "lady companion" for a certain Miss Wilton; and while there saw the worth-while features of London, became well acquainted with its splendid shops, its art galleries and its crowded streets. Visits to Brighton and other bathing beaches on the English Channel were also on her program. Called back to Nürnberg by the death of her father in June of 1850, *Fräulein* Strobel earned her living by giving lessons in English; but shortly she also migrated to Paris and there gave lessons in both English and German. It was at a little German club —the *Teutonia*—here in the French capital that Theodor Diesel and Elise Strobel first learned to know each other; but it was in London, not in Paris, that the two were married on 10 September, 1855. Curiously enough this excursion across the Channel was caused only by the difficulty—the red tape—of getting from the German authorities the papers which would satisfy the French officials.

RUDOLF DIESEL
AT THE AGE OF TWELVE, 1870.

Boyhood and Education

Their son, Rudolf Diesel, was born, 18 March, 1858, at No. 38 rue Notre Dame de Nazareth, just two streets north of Conservatoire des Arts et Métiers, in Paris. But when he was less than a year old his parents moved a few blocks east to No. 49 rue Fontaine-au-Roi, where he spent most of his boyhood and where much of his time was divided between play and helping make portfolios, traveling cases and other leather goods in his father's *atelier*. Here in constant contact with five or six skilled German hand workers, it would be well-nigh impossible for a boy, during the years from eight to twelve, to avoid an intimate acquaintance with the use of tools or familiarity with the more important properties of matter. To this same boy and his pushcart were entrusted many packages from the father's shop to be delivered to customers in various parts of the city. One can imagine how well such a boy learned to know the streets and many of the historic spots of Paris.

Breadth of learning was added by the fact that at home both German and English were spoken. At the Protestant school, which he and his two sisters attended, as well as on the playground, French was of course the one language heard. In his schoolwork marked ability in drawing was evident. However, in spite of all these opportunities, his boyhood was not a period which Rudolf Diesel looked back upon as a happy one.

From early childhood he was self-conscious and proud, an attitude of mind which was unfortunately cultivated by his fond parents alluding, in the boy's presence, to his cleverness and good looks. Notwithstanding these regrettable limitations, the little fellow thrived in an atmosphere which was then full of such new ideas as the storage battery, the balloon, the gas engine, electric lights, dry-plate photography and various novelties in chemistry. He was a frequent visitor at the nearby Conservatoire des Arts et Métiers, the earliest of all the industrial museums of the world. Here Cugnot's three-wheeled steam wagon, already a century old, could hardly fail to catch his attention; for he was mechanically inclined and mechanically gifted.

Then came the *débâcle* of Sedan, followed by an order issued on 6 September, 1870, that all Germans should at once quit the city of Paris. Two days later the Diesel family had arrived in London, had found a couple of cheap rooms in Herbert Street, just east of City Road, and were already searching for work. The young Rudolf was soon in an English school with occasional visits to the South Kensington Museum. Fortunately for the parents, whose modest belongings were locked up in Paris, an uncle in Augsburg had offered to take Rudolf and look after him until the war was over. Accordingly, the young lad of twelve, with his uncle's address on a card tied about his neck, was put on a train and started *via* Harwich, Rotterdam, Cologne, Frankfort and Würzburg, towards Bavaria, a trip which on account of war conditions occupied eight lonesome days.

Once in Augsburg, however, this sturdy, pious, clear-headed boy was immediately placed in a trade school, where he soon acquired a feeling and a conviction that any future success was dependent upon hard work and a mastery of science. He had indeed already learned that good times have to be arranged for in advance. The sterling qualities of three great nationalities—French, German and English—were already evident in the character and habits of this youth. Each of these three important languages he handled with equal ease. At the age of fourteen he had determined upon the career of an engineer. At fifteen he had passed the final examinations at the *Gewerbe Schule* and had gone to Paris for a visit with his parents—his first glimpse of them during the last three years. From this time forward it was evident that Rudolf could hope for no financial assistance from his father. The income from their shop in Paris was too distressingly small.

His distinctly engineering training began in 1873, when he entered the industrial school with a scholarship for a two-years' course in mathematics, physics, mechanical drawing and modern languages. In the summer of 1875 there was awarded him another scholarship covering his expenses for the next two years at the recently founded *Technische Hochschule* in Munich. Here it was in the home of Professor Bauersfeind that young Diesel met a remarkable fellow student, Oskar von Miller, who proved to be a lifelong friend and adviser, later the distinguished head of the Deutsches Museum.

Curiously enough, one of the chief interests of Diesel at this period was the manufacture of mathematical surfaces of the second order, such as hyperboloids and ellipsoids, by the use of plaster of Paris. His first printed paper (1878) was indeed a description of some of these models which were later exhibited at the Columbian Exposition, at Chicago, in 1893 and won for their author a bronze medal. Precision with demonstrable results was now his "ruling passion strong in death."

It was in this same year, 1878, while listening to the lectures of Professor

Carl von Linde on heat engines that the twenty-year-old student became deeply impressed by the low efficiency of the steam-engine with its bulky accessories of furnace, boiler and chimney. He was struck also by the radical difference between those machines which merely transmit power, such as a windmill, water wheel or pulley, and those in which power is, so to speak, created, such as the locomotive. Final examinations at the *Technische Hochschule* coming in July of 1879, found Diesel ill at home with typhoid fever. The parents had recently moved from Paris to Munich. Six months later he was given a special examination, which was passed with flying colors.

Professional Training

In the meantime Professor von Linde, recognizing the rare ability of this young man, had arranged with the Sulzer firm in Winterthur—the engine builders who were making his ice machine—to take Diesel on as a volunteer. At the end of this period of preliminary training Diesel was to go to the factory in Paris, where also the Linde machines were being manufactured. This factory was at Quai Grenelle on the Seine in the western part of the city. Arriving in Paris on 20 March, 1880, Diesel was for some time engaged in assembling and in installing the Linde refrigerators; but before many months had passed he was in full charge of the plant and was acting as engineer, manager, inventor, patent expert and purchasing agent. His duties here, as his son points out, in dealing with the extraction of heat from water and with phenomena in the lower part of the temperature scale proved to be excellent preparation for his own later needs in

MR. AND MRS. RUDOLF DIESEL AT THE TIME OF THEIR MARRIAGE IN 1883.

THE MATURE RUDOLF DIESEL.

transforming heat into work in the higher regions of the scale.

Invention and Development of the Motor

September and October of 1881 have significance in the life of our inventor because it was on these two dates, while he was still making ice machines in Paris, that he took out his first two patents. One of these had to do with the making of clear ice; the other was for a process of producing ice directly in a water bottle such as is used on the table, *carafe frappé*. In the manufacture of these devices, he was led to an acquaintance with Heinrich Buz, director of the Maschinenfabrik at Augsburg. Each of these gentlemen quickly learned to appreciate the other; and thus arose a long friendship which later became a determining factor in the life of the clever

but impecunious Diesel. A keener interest in the profession of mechanical engineering now begins to show itself in a memorandum which he deposits with his *alma mater*. Here he indicates various fields such as transportation, milling, brewing and weaving in which there is an increasing demand for men trained in the practical solution of mechanical problems. To the readers of this memorandum, he introduces himself with a certain lightness of touch as follows:

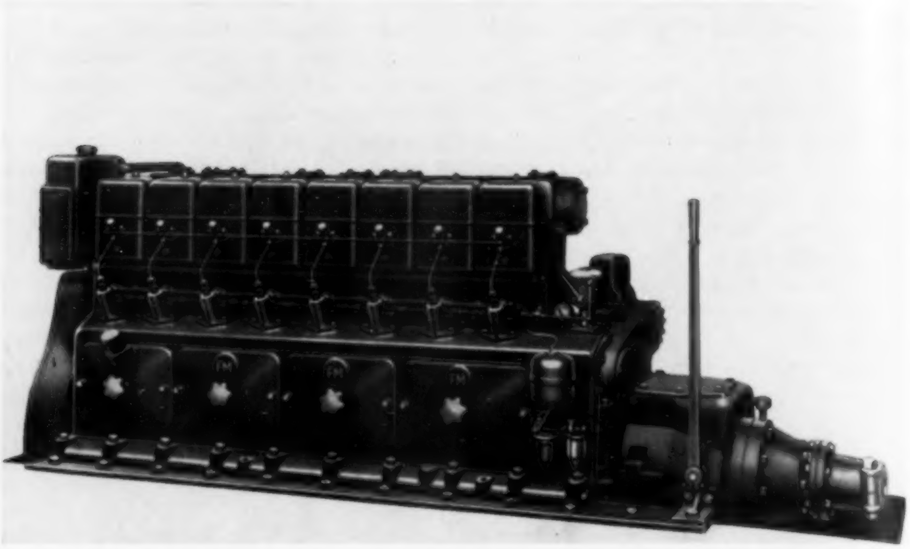
> The undersigned is an ice man, one of the kind who attempts to produce the utmost coolness among men, particularly in the form of ice, ice water, cool air and so forth. This is the type met with especially in our breweries and has recently shown a tendency to expand toward the south. The writer has settled in Paris where he is endeavoring, as a particular aim, to cool the spirit of revenge in the hereditary enemy of Germany.

Things had been going well at the Linde agency on Quai Grenelle in Paris; but Diesel kept thinking of other things. He dreamed of a motor which would operate along the lines of the steam-engine but would use ammonia gas, instead of water vapor, as the working substance. Such an ammonia-motor he had in fact completed in 1889 and thought of exhibiting it at the Paris exposition of that year; but later decided not to do so, mainly because he was just realizing what high temperatures can be produced by compressing a gas. Before the International Congress on Applied Mechanics, which met in Paris on the occasion of this exposition, Diesel gave a lecture on "Refrigerating Machinery and its Field of Application." So perfect was his spoken French that many in the audience took him to be a native Frenchman; and so he was as regards birth, though not as regards citizenship. 'Twas about this time that the gaudy funeral of Victor Hugo (31 May, 1885) took place and that General Boulanger was stirring up hatred against Germany. Such a chauvinistic spirit had a depressing effect upon the sales of refrigerating plants and cold storage devices which had been invented by a German professor and were being manufactured in the German part of Switzerland. Linde also was concerned about the diminishing sales of his inventions in France, and, knowing that Diesel would be glad to leave Paris, he proposed that the young man return to Germany, take up residence in Berlin and manage the business in the northern and eastern part of this country. The salary arrangements—30,000 francs—were satisfactory. Diesel, however, pointed out that he would like to develop and perfect some ideas of his own regarding a new engine. To this suggestion the elder engineer was not very hospitable. Such an attitude of mind on the part of a productive scholar surprised Diesel and made him hesitate; but the opportunity to return to Germany overbalanced all objections and the offer was accepted.

Marriage

Let us now go back half a dozen years in order to pick up another thread. There lived at that time in Paris a prosperous German merchant whose wife was "at home" to her friends every Thursday afternoon. At one of these teas, Diesel and his friend Oskar von Miller happened to meet an attractive and alert young *Fräulein*, Martha Flasche, who had a fluent command of both English and French, and was employed as a tutor in the family of this merchant. To make a short story still shorter, she accepted Diesel's proposal and in the following year they were married at Munich on 24 November, 1883. Another year later their first child was born. Then came a daughter on 15 October, 1885. The third and last child, Eugen, the biographer, whose story I am here briefly sketching, also made his first appearance in Paris. This was on 3 May, 1889.

Curiously enough, Diesel had never been in Berlin until he went there as engineer for the Linde interest in 1890.



AN EIGHT-CYLINDER MARINE DIESEL ENGINE
READY TO BE GEARED TO THE PROPELLER SHAFT OF THE VESSEL. (FAIRBANKS-MORSE.)

The pride of his youth had not yet abated. Accordingly the family was located in a rather pretentious apartment at 113 Kurfürsten Damm, a residential district then on the western edge of the city. A little later they moved into more modest quarters on the north side of the *Thiergarten.* Here in the Prussian capital five years were spent before making their next and final move to Bavaria in 1895.

Berlin Residence

Diesel was immensely pleased with the push and drive which were evident here in the imperial capital, and also with the absence of any political or governmental interference with business. Very shortly he found himself elected to the board of directors of the Market House and Cold Storage Company. Among his many friends—industrialists, army officers and others—he mentions Professor Slaby, who used to say that the two inventors who had made an indelible impression upon him were Diesel and Lilienthal.

By March of 1892 Diesel had given much time, thought and money to improvements upon the internal combustion engine invented by Dr. Otto in 1876. His first patent along this line was granted on 28 February, 1892; and, in order to push these ideas of high compression and elimination of the ignition-spark, Diesel published in January of 1893 a book entitled *"Theorie und Konstruktion eines rationellen Wärmemotors zum Ersatz dem Dampfmaschinen und der heute bekannten Verbrennungsmotoren."*

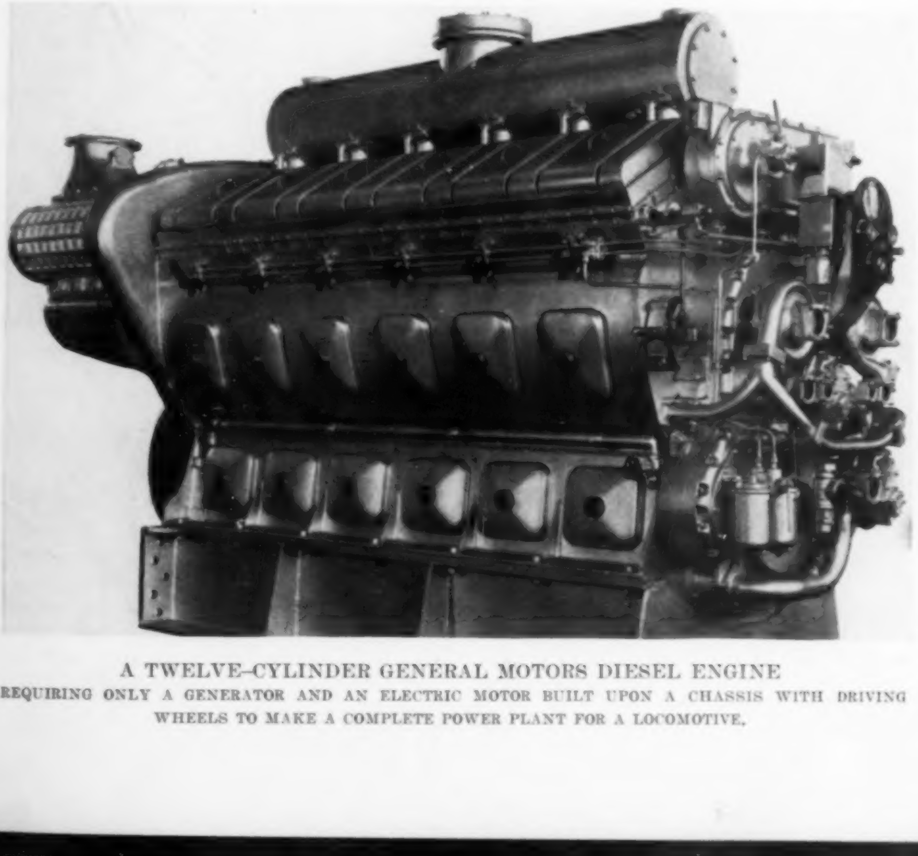
Within a month after the appearance of this volume he had arranged with the Buz factory at Augsburg for the construction of an experimental engine along the novel lines laid down in his patent specifications. A second patent was obtained in 1893 and was soon ceded to the Krupps of Essen, who had already agreed with the Buz firm to help develop the new engine. Diesel was to receive 3,000 marks a year to oversee the work and suggest improvements. A month or so later, 16 May, 1893, the Sulzer company of Winterthur in Switzerland

joined the combination, thus making three important firms who had expressed their interest in the future of the Diesel motor. It was at this time that he closed up his business with the Linde Ice Machine Company and moved to Augsburg where, in the Buz works, an experimental laboratory was built and the assembly of the first motor began. A couple of years later the family moved from Berlin to Augsburg and thence almost immediately to Munich; and here he spent the remainder of his life, except for numerous long business trips to foreign countries, often with his wife as traveling companion.

Development of the Motor

The first experimental machine was ready for trial on 10 August, 1893. It was brought up to speed by an independent source of power. At the instant, however, when fuel was introduced into the cylinder by the feed-pump, a violent explosion occurred. Diesel was immensely pleased with this because he had learned from it that the cylinder walls must be made stronger and—what was more fundamental—that the heat of compression was really sufficient to ignite the fuel. It must not be forgotten that, at this early period, the proper size and shape of the cylinder were unknown, the right amount of clearance between the top of the piston and the end of the cylinder was unknown, and the factory at Augsburg was trying to discover those essential facts which now—a generation after Diesel—are well known, if not to every intelligent boy, at least to thousands of mechanical engineers and skilled workmen all over Europe and America.

A little later this 13-horsepower engine was licked into shape and Diesel became so hopeful, in his characteristic way, that he went to Paris and Ghent in April, 1894, and awakened considerable



A TWELVE–CYLINDER GENERAL MOTORS DIESEL ENGINE
REQUIRING ONLY A GENERATOR AND AN ELECTRIC MOTOR BUILT UPON A CHASSIS WITH DRIVING WHEELS TO MAKE A COMPLETE POWER PLANT FOR A LOCOMOTIVE.

enthusiasm—more indeed than was warranted by later events—over the new invention. For six months more of experimentation showed that the problem was not yet solved; but Diesel, feeling that he had learned much, was undiscouraged. Buz proposed to build an entirely new engine avoiding all the faults of the present one; but it was finally decided to retain the original 13-HP machine and to try gas as a fuel. On 12 October, 1894, the first satisfactory indicator diagram was obtained. The Krupps now sent four men to see the machine in operation. By 28 January, 1897, a second engine had been completed and given a trial which established its success with gasoline as fuel. After five years of continuous and laborious experiment a new engine had been produced which was working smoothly and was showing greater thermal efficiency than any other engine in existence. Interest was expressed by the ablest engine builders of France, England, Belgium and Germany. Yet Diesel was not forgetting that his original problem of using crude oil—and even powdered coal—was still unsolved. He knew also something about the vulnerability of patents, and he knew only too well that the value of a patent depends largely upon the strong will, brains and ability to win friends which lie back of it. In spite of these conditions, his

General Motors Corporation.

A MODERN STREAMLINED PASSENGER TRAIN

HAULED BY A DIESEL LOCOMOTIVE. THIS ENGINE WITH ITS HIGH THERMAL EFFICIENCY, CLEVER DESIGN AND ACCURATE WORKMANSHIP, IS THE ONE EMPLOYED IN THE "CITY OF SAN FRANCISCO," THE "400," THE "BURLINGTON ZEPHYR," THE "CAPITOL LIMITED" AND OUR OTHER BEST TRAINS.

son and biographer considers the spring of 1897 as the climax of his father's career. For the Augsburg company and the Krupps now felt so much confidence in the patents that they guaranteed Diesel 50,000 marks annually for his royalties. A few weeks later a Scotch firm (the Mirrlees Watson Yaryan Co.) after a conference between Diesel and Lord Kelvin, agreed to pay him 20,000 marks annually for his patent rights. A yearly income of 70,000 marks was not only a new experience for the impecunious inventor, it was evidence that in the opinion of these leading firms the "infantile diseases of the new invention" (*Kinderkrankheiten neuer technischer Schöpfungen*) had been successfully passed. It was in September of 1897, at Baden-Baden, that Adolph Busch, of St. Louis, first met Diesel. A contract for the manufacture of the engine in America was signed almost immediately; and the Busch-Sulzer Company of St. Louis is to-day to be reckoned among the important manufacturers of this product.

On 17 September, 1898, a new German Diesel Motor Company was formed, not a manufacturing concern, but merely a combination which held the patents. It was, in fact, a holding company which paid Diesel 1,250,000 marks in cash besides giving him a large number of shares of stock. The forty-year-old inventor naturally considered himself a wealthy man: and the family moved into a commodious and handsome apartment in Munich. Elaborate offices were set up in the adjoining apartment. A little later a large and expensive house was built. Enormous investments in oil-fields and other pieces of real estate were made. And all this was done in apparent forgetfulness of the fact that his patents were now owned by the General Diesel Motors and were therefore entirely out of his hands. He forgot also that the interval which engineers call "the period of development" is generally a long one—often ten to thirty years. His familiarity with motors far exceeded his financial judgment and his knowledge of the stock market.

The press of business which he now encountered made serious inroads upon his health, which he tried to repair by the use of *antipyrin* and bromides. The buoyancy and over-confidence of this generous soul were evident in nearly everything he did. It was not long, however, before the real estate declined in value, the oil-wells ceased to pay and the cost of maintaining the large residence could not be met. The Augsburg factory in which he was a large shareholder dissolved in 1911. Further inroads were made upon his peace of mind by lawsuits. Yet withal the evidence is that Diesel was essentially modest, always carried a fine spirit, always kept his troubles to himself; qualities which call for courage.

We return now to the story of the motors. These were first publicly exhibited in 1898 at the Mechanical Exposition which was held in Munich on the site of the present Deutsches Museum. Of the four engines there shown, one was made by the Krupps, one by the factory at Augsburg, one at Nürnberg; and the fourth, built by the Sulzer Motor Company, was employed to drive the liquid-air machine devised by Diesel's teacher, Carl von Linde of Munich.

This combination of a heat engine with a refrigerator to produce the exceedingly low temperatures of liquid oxygen and nitrogen is cited by the biographer as an impressive illustration of the fact that, in the modern theory of physics, heat and cold belong to one and the same category.

Among the outstanding scientific novelties at the Paris Exposition of 1900 was a group of five Diesel motors, four of them built in France, the other one at Augsburg. It was here, on the turn of

the century, that Diesel first had the pleasure of meeting Count Zeppelin at the launching and trial trip of "Zeppelin, I" in June of 1900. The realization, however, of Diesel's hope that a dirigible should be driven by one of his engines, was delayed for 35 years and hence to a time long after his death. Another group of Diesels was shown at the St. Louis Exposition in 1904; and one of them, indeed, is in use to-day (1940) at Key West in Florida. The General Motors Corporation at the Century of Progress Exposition in 1933 derived the power for their assembly line from a set of powerful Diesel motors which attracted a steady stream of visitors and adumbrated the great factory of the Electromotive Corporation at La Grange, Illinois, where no less than 3,000 men are to-day engaged in equipping streamlined trains—both passenger and freight—with Diesel locomotives. The era of the small Diesel motor began about the time of the Brussels Exposition in 1910. A four-cylinder engine of this period was applied to an automobile and is now preserved in the Deutsches Museum. But hundreds of them, far from being museum specimens, are now driving long-distance trucks in America.

A new chapter in the history of these motors opened in 1912, when the *Selandia*, a large ocean-going vessel built in Copenhagen, completed her first long voyage to and from Bangkok, the capital of Siam. For this achievement suggests that the introduction of the Diesel marine engine—now proceeding rapidly—is possibly the greatest improvement in ocean navigation since the substitution of steam for wind propulsion. Amundsen had already employed this same type of motor in Nansen's ship, the *Fram*, on his trip to Antarctica in 1910. Thirty years later Dr. Thomas C. Poulter used two Diesel engines in his *Snow Cruiser* in these same polar regions. The rapidity with which the marine Diesel has been adopted is not a matter for surprise, since the latest steam turbines give an efficiency of only 29 per cent., while a good Diesel yields as high as 37 per cent. Shortly before his death Diesel addressed a meeting of English shipbuilders and, at the dinner which followed, was seated at table beside Sir Charles Parsons, the pair thus representing a good-natured rivalry between the two heat engines, the steam turbine and the Diesel motor.

Visits to America

His first trip to the United States was a hasty one made in 1904 on the occasion of the Louisiana Purchase Exposition at St. Louis. On his second voyage, in March of 1912, he was accompanied by Mrs. Diesel. They visited Cornell University, the Naval Academy at Annapolis, St. Louis, and other places of scientific and academic interest. The 6th of May found them at Orange, N. J., for a visit with the Edisons, who shared with the Diesels the friendship of Oskar von Miller. The simplicity, the directness, the energy and the abstemious habits of Mr. Edison made a deep impression. His playful parting message, as they left his home, was "Don't eat too much!"

The Catastrophe

The last few years of Diesel's life were filled with intense labor. He was constantly making new plans, lecturing and traveling. Financial troubles increased when he entered the speculative field, where costly mistakes were made because he was totally unacquainted with the weapons there used. Teeming with energy and pride, exceedingly sensitive in mind and heart, he was capable of great suffering, and he did suffer intensely.

The spring of 1913 found the Diesels—husband and wife—in Sicily, where, under Italian skies, they deeply enjoyed visiting historical spots. The only cloud in the sky was the publication at this time of Lüders' book minimizing—not to say slandering—Diesel and his achievements—an unwarranted and painful attack.

It was in June, 1913, that the Diesels gave a reception in their big Munich house to several hundred American engineers; and were invited to visit the San Francisco Exposition of 1915, with transportation through the Panama Canal on the *Fram*.

In September of 1913 appeared his book *"Die Entstehung des Diesel Motors,"* the outcome of a lecture he had given in the preceding autumn before a group of naval architects. In the concluding pages of this volume the author has given us some of his philosophy of life. His sentences, though not quite so brief, remind one of the maxims from *Poor Richard's Almanac.* Space permits only two or three extracts.

> An invention consists of two parts: the idea and its execution.
>
> An invention is never a purely intellectual product, but is the result of a battle between the idea and the material world.
>
> The birth of an idea is the happy moment in appears possible and reality has not yet entered appears possible and realtiy has not yet entered into the problem.
>
> The inventor must be an optimist since the full driving power of an idea is to be found only in the mind of the originator. He alone has the sacred fire to push it through.

Visits with his younger son to the old familiar places in the Bavarian Alps and calls upon long-time friends had occupied much of the summer of 1913. He set his Munich house in order and accepted the invitation of George Carels, a fellow engineer of Belgium, to come *via* Ghent and join him on a trip to London for a conference meeting there on the 30th of September. It was planned also to attend the inauguration of a Diesel factory at Ipswich. On the 26th of September he went with his younger son to Frankfort, where his wife and daughter had preceded him. After a delightful visit of two days, including an excursion to the neighboring hills, the son accompanied the father to the railway station, where a first-class ticket—unusual for Diesel—to Ghent was purchased. The father bade the boy an affectionate farewell, and was thus seen for the last time by any member of his family. On the 29th of September, writing from Ghent, he sends loving messages to his wife and to each of the children.

His traveling companions, Messrs. Carels and Luckmann, report that they had dinner with Diesel on board the steamer *Dresden* after embarking at Antwerp. Dinner over, they enjoyed a stroll up and down the deck; then each to his stateroom. These two friends, not finding Diesel on deck as the steamer was arriving in Harwich, went to his room, but their knock was not answered; so they opened the door, only to find that the bed had not been slept in. A thorough search of the vessel proved that he was not aboard. The family was notified. No trace of the body was ever found.

The contents of his safe at Munich showed that his property had dwindled during recent years to practically nothing. The price of Diesel stock in the English company fell at once from 12 shillings to 5; and then to 2 shillings. "It is difficult to imagine," said an English friend shortly after his death, "anything more delightful than his private life. Well balanced, he appeared to combine the thoroughness of the Germans with the culture of the French. He possessed that modest self-control which one finds in a high-class American. There was in him no trace of snobbishness or mediocrity."

We shall probably never know which alternative to accept: self-destruction or the enmity of some jealous rival. We are certain only that his generous heart found peace at the bottom of the English Channel, where to-day that heartbreaking folly called war is sending so many brave souls to keep him company. We grieve that he never lived to see his ideas come to full fruit.

PHYSICAL EFFECTS OF EXTREME PRESSURES

By Dr. ROY W. GORANSON

GEOPHYSICAL LABORATORY, CARNEGIE INSTITUTION OF WASHINGTON

IT is well known that many of the physical properties of a substance can be materially changed by applying external pressure to the system. Even so, the question may still be asked: What kind of valuable information may be expected from further high pressure investigations and what usefulness may such investigations have? This question can not be answered by merely reviewing specific examples of pressure effects, but requires a correlation of our present knowledge and an exploration, by means of theoretical considerations, of the still unknown regions of pressure phenomena.

GENERAL RELATIONS

Temperature and pressure both rise with increasing depth in the earth, attaining values of the order of 3,000° C. and 3,500,000 bars at the center (1 bar $= 10^6$ dynes/cm^2 = 0.987 atmospheres = 14.5 lbs/in^2). The behavior of matter at very high pressures is thus one of the outstanding problems of both geophysics and physics.

The program initiated by the Geophysical Laboratory of the Carnegie Institution of Washington, organized in 1908 for a study of the physical properties of the earth and its constituents, therefore included as fundamental both high temperature and high pressure investigations. At about the same time a program of high pressure research was also begun at Harvard University by P. W. Bridgman.

Pressure and temperature may be correlated by means of thermodynamics. From these relations it is seen that pressure acts in an opposite manner to temperature and thus opens up a field that can not be deeply surveyed from the temperature axis alone. If a solid is heated it expands, eventually melts and finally evaporates; if now this vapor is compressed it retraces these steps provided it is below its liquid critical temperature, *i.e.*, the temperature above which the liquid state can no longer exist. With further increase in pressure, however, this solid may break down again and again into other crystalline forms which are stable only at high pressures and are successively closer packed (denser) and more symmetrical (tending toward isotropicity) in configuration. A classic example of such a system is water, for which Bridgman has found six different pressure forms of ice. If we move out into the pressure field along the $-40°$ isotherm we find successively ice I stable to 2,080 bars; ice II, stable from 2,080 to 4,490 bars (ice III is a higher temperature modification of ice II for the pressure region from 2,130 to 3,440 bars and ice IV is non-existent); ice V, stable from 4,490 to 6,225 bars; ice VI, stable from 6,225 to 20,600 bars; and ice VII, stable above 20,600 bars. Ice VII at 50,000 bars is more than twice as dense as ice I at atmospheric pressure. It is also interesting to note here that, unless the pressure-melting curve of ice VII has an improbable maximum or asymptotically approaches some value lying below 374° C., the liquid state must cease to exist at pressures in the neighborhood of 75,000 to 100,000 bars.

The mutually antagonistic effects of temperature and pressure are best studied by consideration of the free energy

(thermodynamic potential) relations. In ordinary mechanics the equilibrium state of a system is specified by the minimum of its potential energy (energy of position). Where thermal changes must be treated it is necessary to extend this concept by use of the Second Law of Thermodynamics. The relation so obtained has been called the "maximum work," "free energy" or "psi" function, and with it we are able to probe homogeneous stability relations. For example, the "psi" of a compressed gas is equivalent to the maximum work it could do on release of the external pressure at constant temperature. In the still more general problem which takes into account heterogeneous, or phase, equilibria, *i.e.*, of such systems as solid–liquid, liquid–gas, or solid A–solid B, a further extension is required. The expression deduced has been called the "free energy," "thermodynamic potential" or "zeta" function. Here, too, the equilibrium condition is that of minimum free energy. Thus a metastable system is one containing excess free energy which is released on transition to a more stable phase. Many of these unstable modifications persist for considerable periods of time and such examples are all about us. An extreme case is the unstable uranium atom. Fission of one pound of these atoms would release the equivalent of the energy obtained by burning 3,000 tons of coal. Temperature metastability is exemplified by quenched or frozen systems—the best known is window glass. A striking example of pressure metastability is diamond, which is discussed later.

A reaction that is promoted by increase in pressure is inhibited by increase in temperature, as is evident from Figs. 2 and 3, discussed later. The initial ratio of the two effects differs from system to system, but, as a rough order of magnitude, a pressure of several hundred bars is required to compensate for a ten-degree rise in temperature.

Theoretical Developments

In the last thirty years considerable data have been accumulated to pressures of a few ten-thousand bars, but only recently has any serious attempt been made to extend the range of pressure materially. Recent developments in the field of theoretical physics have, however, been very provocative in that vistas have been opened up concerning the properties of matter at very high pressures. From such studies it may be deduced that at sufficiently high pressures all matter tends to behave in a uniform manner. Pressure-volume relations applicable at very high pressures have been computed by H. Jensen[1] from a modification of the hypothetical Thomas-Fermi atom model. These relations are initially functions of the atomic nuclei but approach asymptotically the pressure-volume curve of a homogeneous electron gas model at extremely high pressures. The curve for the element of atomic number 26, which is iron, is illustrated in Fig. 1. Distinctions, as we know them, between solids, liquids and gases must finally vanish. Extrapolation of the experimental curve for iron to the theoretical curve shows that these relations become valid for metals only at pressures exceeding those found at the center of the earth.

Again, certain metals of the transition series of elements—for example, iron, cobalt and nickel of the first transition series and gadolinium of the third, or rare earth, series—together with certain compounds of these elements possess a relatively rare physical property known as ferromagnetism. These substances are made up of a great many regions or domains in each of which the magnetic moments of the atoms are parallel. If these domains are large enough to enclose a considerable number of atoms (of the order of 10^{14}) they can be reoriented into any desired direction by suitable

[1] H. Jensen, *Zeit. f. Physik*, 111: 373–385, 1938.

external magnetic fields. When the energy of motion, obtained from increase in temperature, becomes sufficient to exceed the "interaction forces" by which a domain is bonded together, then the substance loses its ferromagnetism and this temperature is known as the Curie Point.

From some other concepts it is inferred that, although in certain instances the Curie Point may be raised initially by pressure, ultimately at sufficiently high pressures this property of ferromagnetism will cease to exist at any temperature. The basis of such a prediction is somewhat related to a familiar principle, namely, that two bodies can not occupy the same space at the same time, except that for this argument one must deal with an n-dimensional phase space. From the present-day accepted theory of atomic structure the electron of an atom system may be specified by certain quantum numbers of which electron spin is one of the coordinates. Assume now that we have two such systems each with an electron of similar phase coordinates, including parallel spins which thereby impart a net magnetic moment to this ensemble. If these two systems are now squeezed closer and closer together their phase space fields will begin to overlap and at some critical distance of approach they must separate by moving to different parts of this phase space. This movement occurs along the spin dimension because it is the path of least resistance. The electrons thereupon switch to antiparallel spins and the ensemble loses its magnetic moment. The external pressure needed to squeeze the systems to this stage is estimated to lie in the neighborhood of a million bars.

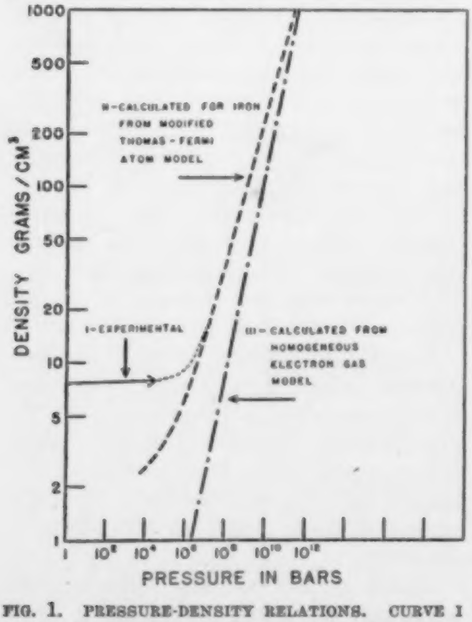


FIG. 1. PRESSURE-DENSITY RELATIONS. CURVE I GIVES THE EXPERIMENTAL VALUES FOR IRON. CURVES II AND III WERE COMPUTED BY H. JENSEN. ATTENTION IS CALLED TO THE GAP BETWEEN CURVES I AND II, INDICATED IN THE DIAGRAM BY THE DOTTED PORTION, WHICH LIES BETWEEN 12,000 AND 10,000,000 BARS PRESSURE.

It should be noted here that these effects of temperature and of pressure on ferromagnetism are very different; temperature breaks up the alignment of the magnetic moments in the domains, whereas pressure destroys the source of these moments.

The intermediate pressure region lying between ten thousand and a million bars is still somewhat of a wilderness requiring the cooperation of experimental and theoretical physics for its exploration. Experimental work on the elastic, electric, magnetic and other physical properties of matter at very high pressures, such as changes in crystalline state and chemical composition, is very much to be desired. Plausible theories that may be replaced by many other equally probable hypothetical pictures can not be considered as having satisfactorily explained anything, and this is the state of affairs concerning our knowledge of the interior of the earth, its constitution, composition and magnetic properties.

Pressure Transformations

It is only recently that a choice could

be made of the many suggested explanations for deep focus earthquakes, *i.e.*, those initiated at depths of about 700 kilometers. By a process of elimination it can be shown that they are probably the result of a temperature–pressure–phase change mechanism.

This mechanism is operable if the material at a depth of 700 kilometers can exist as either of two forms A or B, B being denser, and the temperature is such that fluctuations in the thermal gradient may effect the transformation from one form to the other. Lowered isotherms then induce the change $A \rightarrow B$ with accompanying collapse, and raised isotherms the change $B \rightarrow A$ with expansion. From a study of the earth's past history we learn that large temperature changes must have occurred. Moreover, certain periodicities may also be adduced, and if these are used in conjunction with the above mechanism we have in addition a plausible explanation of crustal uplift and downwarping.

Pressure–phase transitions are as a rule reversible, *i.e.*, the change from B to A with falling pressure occurs as readily as that from A to B with rising pressure. A large number of these reactions, however, are very sluggish at low temperatures. Thermodynamically the efficiency of a pressure reaction, *i.e.*, the completeness of conversion, increases with decreasing temperature. Practically this is not the case and, in order to obtain a reasonable or finite rate of reaction, special procedures must be used. One of these is to supply the system with excess energy, called activation energy, accomplished by superpressing the substance far above the equilibrium pressure or by working at higher temperatures. Another method is to reach the desired state *via* a series of intermediate processes, as by introduction of a catalyst to induce surface chain reactions or by crystallization from solution. Efficiency in conversion must in practice be sacrificed for higher rates of production.

The following may be a suggestive, even though imperfect, analogy: The lowest potential energy level, and therefore most stable position, of a boulder resting on a saucer-like depression on the slope of a hill is on the valley floor below. In order to reach this lower level work must be done on the boulder in order to push it up over the edge of the depression, which constitutes an energy barrier. If now the region is subjected to a series of earthquakes the boulder will begin to oscillate in the saucer. Finally one of its oscillations may bring it up and over the lip of the saucer, whereupon it starts down and, by acquiring sufficient momentum, hurdles other saucer-like depressions farther down the slope until it reaches the bottom. This would constitute the "activation energy" method of initiating movement. Transfer by the "catalytic" method would be accomplished by replacing the saucer with a series of saucers having correspondingly shallower depressions. Oscillations too small to carry the rock over the lip of the single saucer can start it along this train and, after hurdling the first one, it gains sufficient momentum to carry it through the others. A variant of the "activation" type of process, used in atomic physics, is bombardment by a projectile of sufficient mass and velocity to knock it out of the saucer.

It is possible to quench, *i.e.*, freeze, the high pressure modification of such sluggish systems and take it down to atmospheric pressure for examination. One of these substances is carbon, which exists in two crystalline forms, graphite and diamond. It has stirred the imagination of many aspiring diamond synthesizers and, to answer the many requests for information, a temperature–pressure phase diagram was computed for the graphite–diamond reaction, of which Fig. 2 is an up-to-date version. Graphite exists stably in the temperature–pressure region lying to the left of the curve, and diamond exists stably in

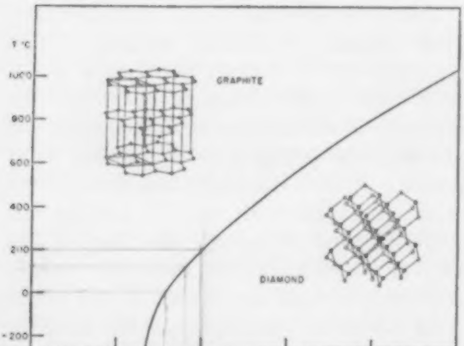


FIG. 2. THE STRUCTURAL MODELS OF GRAPHITE AND DIAMOND DESIGNATE THEIR RESPECTIVE STABLE REGIONS FOR DIFFERENT CONDITIONS OF TEMPERATURE AND PRESSURE. THE CURVE REPRESENTS THE BOUNDARY SEPARATING THESE FIELDS.

the region to the right of the curve. The latter is therefore unstable at pressures below 13,000–14,000 bars and, but for the high energy barrier between it and graphite at low temperatures, it could not exist at the surface of the earth.

The space-lattice crystal structures illustrated in Fig. 2 show very clearly the striking differences in the physical properties of these two substances. The circles represent the centers of carbon atoms, and the reciprocal of their separation is a function of the strength of the bonds holding them together. The planes of easiest cleavage are thus those across which the separation is greatest. In this connection it is interesting to note that the diamond lattice may be obtained from the graphite lattice by means of an axial compression and rotation.

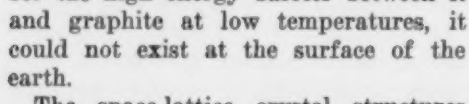


FIG. 3. PERCENTAGE OF CONVERSION OF NITROGEN AND HYDROGEN TO AMMONIA FOR DIFFERENT TEMPERATURES AND PRESSURES. IT INCREASES THEORETICALLY WITH INCREASING PRESSURE AND DECREASING TEMPERATURE.

Practical Uses

The more important practical utilizations of pressure are those concerned with changes in chemical constitution and known as pressure–phase or heterogeneous equilibria. Pressure synthesis may perhaps justly be said to have originated with work on the amine dyes, but its real impetus began about 1910 with the Haber–Bosch process for fixation of nitrogen from nitrogen and hydrogen to form ammonia. Equilibrium curves for the reactants nitrogen, hydrogen and ammonia have been plotted in Fig. 3 from data of the Fertilizer Research Division of the Bureau of Plant Industry, U. S. Department of Agriculture.[2] For example, at 500° C. and 410 atmospheres, indicated in the diagram by an arrow, ammonia constitutes a third of the mixture. It will be noted also that the yield should increase with increasing pressure and decreasing temperature, but in practice catalysts and temperatures of 400 to 600° C. are used to push the reaction along.

The synthesis of methanol and ethanol, and the hydrogenation of coal, oil and other carbonaceous matter are typical examples of similar processes. Active research is also being prosecuted on the synthesis of higher alcohols. Another type is exemplified by the cracking of oils and fats under pressure.

Other applications of higher pressures might be made in such varied fields as (*a*) polymerization processes, which are very important to the plastics indus-

[2] Fertilizer Research Division of Bureau of Plant Industry: A. T. Larson, *Jour. Am. Chem. Soc.*, 46: 367–372, 1924.

try; (*b*) pasteurization and sterilization by hydrostatic pressure in cases where high temperature is destructive to the compounds; (*c*) increased rates of production for certain reactions; for example, the research department of the Imperial Chemical Industries (British)[3] has found that the rates of certain "slow" reactions in the liquid phase, such as that between pyridine and ethyl iodide in acetone, are accelerated about ten times at 3,000 bars, fifty times at 8,000 bars, and perhaps several thousand times at 20,000 bars pressure; (*d*) purification and concentration of materials. Solubility and melting point relations are changed by pressure, and these rates of change in general vary for different substances. Separations by fractional crystallization (freezing) which are difficult or impossible at atmospheric pressure may be readily made at higher pressures under certain conditions. These conditions can be predicted from heat and volume changes on freezing of the various components of the mixture. For instance, the melting temperatures of cyclohexane, benzene, and nitrobenzene are, respectively, 6.55, 5.50 and 5.70° at one atmosphere, but 58.7, 32.7 and 27.9° at 1,000 bars pressure.

Non-Uniform Compression

The processes illustrated above, wherein no attempt has been made to cover the whole field, are hydrostatic (uniform) pressure effects. There is another large field of very different pressure phenomena for which the compression is not the same in all directions (non-uniform) and not the same on all the reactants. Such compressed substances are said to be stressed.

The design of high pressure apparatus is in itself a study of non-uniform high pressure phenomena and these are therefore combined in the following discussion.

The experimental difficulties under which high pressure work is conducted are in general so different from everyday engineering experience that a large store of knowledge concerning the behavior of metals under extreme conditions has perforce been gained which might not otherwise be available to-day.

The growing interest in high pressure work is made evident by the rapidly increasing number of requests for assistance in design of apparatus. Publication of special assemblages is helpful, but, as no two problems are identical, it is more efficient and satisfactory to design the apparatus for the job rather than attempt to adapt an arrangement built for another type of work. There are certain fundamentals that must be fulfilled in any satisfactory construction, and some of these will now be discussed.

All the features of good engineering practice are adhered to where possible except that in experimental research safety factors are necessarily—although, it is hoped, intelligently—ignored where the ultimate in pressure is sought.

Apparatus for pressure work consists essentially of one or more steel vessels into which access must be had for pistons, connections, and electrically insulated electrodes.

Pressure Connections

Considerable attention has been given to seals for the various types of closures. They must be designed so that the stress developed *across* the contact surfaces making the seal between the interior and exterior of the vessel exceeds the pressure difference along the contact surface in order that the joints be leak-proof. For low pressure work this stress may be developed by tightening up nuts against the internal pressure. At high pressures this type of closure can be and is being made to function, but here the

[3] Imperial Chemical Industries (British): R. O. Gibson, E. W. Fawcett and M. W. Perrin, *Proc. Roy. Soc.*, A150: 230–240, 1935; M. W. Perrin and E. G. Williams, *Proc. Roy. Soc.*, A159: 162–170, 1937.

tightening must be done not with nuts but with continuous application of hydraulic pressure.

Seals which can be tightened up against internal pressures to 6,000 bars have been adapted from those designed by the Geophysical Laboratory, under the direction of L. H. Adams, for the Nitrate Division of the United States Ordnance Department in 1918. Such connections are now obtainable commercially and their use appears to be standard practice in this country to-day.

A simple but very effective method of making leak-proof connections, first used by Amagat and later developed by P. W. Bridgman and by the Geophysical Laboratory, can be adapted to a variety of purposes. Bridgman has named it the "unsupported area" principle. Some of these connections, chosen at random, are illustrated in Fig. 4. The unsupported area is the area exposed to the lower pressure side, and the differential closure stress is equal to the internal pressure times the ratio of the unsupported area to the packing area. If the closure stress is too high, failure will occur by shear or rupture of the packing stem, and if too small, the joint will leak. Moreover, for moving parts, such as pistons, the packing should be designed to have a minimum frictional drag. In this figure the arrows indicate the acting direction

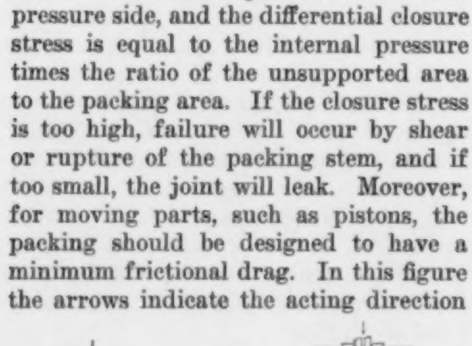


FIG. 4. EXAMPLES OF HIGH PRESSURE CLOSURES (A), CONNECTIONS (B, C, E, I), PISTON PACKINGS (D, F), AND INSULATED ELECTRODE PACKINGS (G, H).

of the internal pressure. Fig. (4, A) is the simplest example of such a closure which, in order to remain leak-proof, must have perfectly fitting contact surfaces. It was first used for glass windows in pressure vessels by T. C. Poulter.[4] Fig. (4, B) shows a joint seal made by a hardened ring with an outer cross-section in the form of a sine wave. To be leak-proof it must be a perfect fit, but this is easier in practice than with Fig. (4, A) because the contact surfaces can be made much smaller. Fig. (4, C) is an older but more generally useful variant developed by the Geophysical Laboratory. The two sealing surfaces are tapered at slightly different angles so that they are in contact only along a very narrow strip. The pressure load on the inner tapered bridge is transferred to the two supporting ends, one of which is the surface of seal. The sealing stress thus exceeds the leak pressure. The other packings shown here all have a fixed ratio of sealing stress to internal pressure, which means that at some value of pressure the packings will cut into and pinch off the adjacent metal. Seal (4, C) has the advantage that the contact surface increases and the unsupported area decreases by virtue of the bending of the tapered bridge with increasing internal pressure. It has been used for closures, packing plugs, dead-weight gage piston packings and pipe connections. All the rest of the packings listed here depend on the use of a plastic material which will flow into and close up any irregularities that may be present. Of these (4, D) is a piston packing in which the seal is made by using rubber together with rings of triangular cross-section which may be brass, phosphor bronze or beryllium copper, depending on the pressure. The purpose of these rings is to prevent the rubber from squeezing out of its allotted space. The unsupported area is given by that of the mushroom stem. Fig. (4, E) shows a

[4] T. C. Poulter, *Phys. Rev.*, 40: 860, 1932.

pipe connection sealed with rubber which is prevented from squeezing out by rings as indicated in (4, D); (4, F) illustrates a method of sealing around a moving piston. The packing materials are similar to those shown in (4, D). Fig. (4, G) shows an electrode packing made from lithographic limestone, talc and rubber; these also insulate the stem electrically from the metal container. Fig. (4, H) illustrates another form of electrode packing, but here the packing barrel, as far as the plug seal at the 45° incline, lies inside the pressure chamber and is thus supported by the internal pressure. Fig. (4, I) shows a pipe connection in which the plastic substance making the seal is retained by two steel rings; the unsupported area is here indicated by the triangular cross-section above the rings. Examples (4, C), (4, E) and (4, I) may also be used to seal up unused openings.

The maximum pressure that can be developed in an apparatus is determined by the strength of its materials. One of our problems is therefore concerned with a search for materials which, after preliminary temperature and pressure treatment, will meet the requirements. A pressure assembly consists of several different materials because the physical properties needed in the various parts are not the same and no one material has all the requisite characteristics.

High compressive strength is needed for pistons. Glass-hard tool steels have a compressive strength in the neighborhood of 30,000 bars. On the other hand, carboloy, which consists of tungsten carbide particles cemented with cobalt, is twice as strong as steel in compression and is thus the strongest known material under ordinary conditions. These materials are not homogeneous, however, and consequently are highly variable in behavior. It is deduced from certain theoretical considerations that, under different external conditions, described later, several other materials may become superior. Natural substances contain impurities and flaws so that a controlled synthetic product is desirable; one such substance is corundum, better known by the gem names ruby and sapphire.

High compressive strength is usually accompanied by the property of brittleness, so that for these materials there is practically no preliminary plastic flow before rupture under ordinary tension. Consequently, the presence of inhomogeneities and localization of high-stress regions in these substances prevent an even distribution of load over their cross-sections and they fail in tension long before the theoretical strength can be realized. A compromise must therefore be made in order to obtain sufficient ductility or plasticity to insure that these localized high-stress regions can be eliminated by redistribution before rupture occurs.

Considerable success has recently been attained in the Geophysical Laboratory with the use of certain ferrous alloys containing relatively large amounts of certain elements such as tungsten, chromium, vanadium, cobalt, and molybdenum. These alloys are subjected to a special kind of heat treatment which involves a delayed quench and repeated tempering draw. Under these conditions they become very hard and strong, yet exhibit a certain amount of ductility before failure; in other words, localized high-stress regions ordinarily present in hardened substances have been removed by this method of heat treatment without noticeably sacrificing hardness, an achievement not heretofore realizable with the older types of steels. This material is particularly adaptable for certain parts, such as the mushroom heads of pistons and electrode stems shown in Fig. 4, where the ultimate in both tensile and yield strength is desired.

Pressure Seasoning of Cylinders

When the inner bore layers of a pressure vessel are under internal pressure

they reach their elastic limit in tension before the exterior wall layers do, and this difference is accentuated by increase of wall thickness. If the elastic limit, or yield point, in tension is equal to the ultimate tensile strength, the cylinder wall ruptures from the *inside outward* without any preliminary warning. If, however, a considerable gap exists between these two stress limits the inner bore wall first yields plastically, *i.e.*, becomes permanently stretched, and transmits further increase of stress to the outer layers. This process can continue with further growth of the yield or plastic zone until this gap in the two properties becomes bridged at the bore wall or until the outermost layers become stressed to their tensile limit, whereupon the wall ruptures by tearing from the *outside inward* and gives warning by the stretch of its outer diameter.

To have the cylinder wall act as an elastic unit in supporting the internal pressure or, in effect, to increase elastic strength at the inner bore wall, an initial stress distribution must be set up such that the tangential, or hoop, stresses are tensions at the outer layers and compressions at the inner layers. This may be obtained by (*a*) shrinking thin sleeves one on the other to form a built-up cylinder, (*b*) wrapping wire under tension around the cylinder, (*c*) subjecting the vessel to a preliminary internal pressure seasoning, or "autofrettaging," in excess of the desired operating pressure, or (*d*) maintaining the interior wall at a higher temperature than the exterior wall.

This kind of preliminary treatment to prevent stretch in the bore diameter is essential not only for high-pressure cylinders but also for long-range guns in which high pressures are developed by the explosives. It may therefore be of interest to consider this technique in more detail.

The stresses set up in the walls of a steel cylinder with autofrettage pressure applied and with it removed are plotted in Fig. 5. The ratio of outside to inside diameter is three to one. The material is a cannon steel (technically, about S.A.E. 4,330) and one of the few for which quantitative calculations are possible because complete push-pull load-extension diagrams are available.

In this figure the cylinder cross-section is plotted with its axis horizontal, R_i denoting the internal radius and R_e the external radius. The radii R_p to R_i (the plastic zone) and R_y to R_p (the yield zone) are the regions wherein the stresses are above, and R_e to R_y (the elastic zone) the region below the yield point of the steel. The narrowness of the latter zone indicates that this cylinder is being frettaged close to its limit. The stresses set up with the autofrettaging internal pressure applied are plotted in the upper cross-section of the wall. The residual stresses after release of this pressure are plotted in the lower cross-section of the wall. Negative values of stresses or points lying to the left of the broken line are compressions, and positive values or those to the right are tensions. The stress "*S*," although actually hypothetical, gives a good account of the behavior of cylinder walls and, moreover, can be directly correlated with ordinary stress–strain tensile test measurements.

After such a preliminary pressure seasoning, the bore wall of the cylinder reacts elastically for internal pressures up to the frettaging pressure and is thus 2.5 times stronger elastically than the bore wall of the unfrettaged cylinder. An increased longevity of the cannon may be secured by a subsequent low temperature treatment to level off some of the high-stress points set up by the presence of inhomogeneities and impurities in the metal.

The gain in elastic properties of steel by proper heat treatment decreases with increase in thickness of the piece. Furthermore, the elastic resistance of a pressure vessel is limited by the residual

compressive stress that can be built up in the inner bore layers. This is less than the compressive strength as determined from test specimens because of the previous overtensioning in the autofrettage process. These two factors set a limit to the useful wall thickness of pressure vessels, but this may be removed in part by the use of built-up cylinders using some of the new materials now available.

Apparatus for High Temperature and Pressure Work

As was stated earlier, temperature and pressure are mutually antagonistic in their effects, but many important pressure relations can be studied only at high temperatures. Some of these are phase relations in silicate systems, *i.e.*, in the stuff that makes up the earth's crust, solubility and melting point determinations, electric and magnetic studies. Furthermore, some pressure reactions can be made to proceed only at high temperatures.

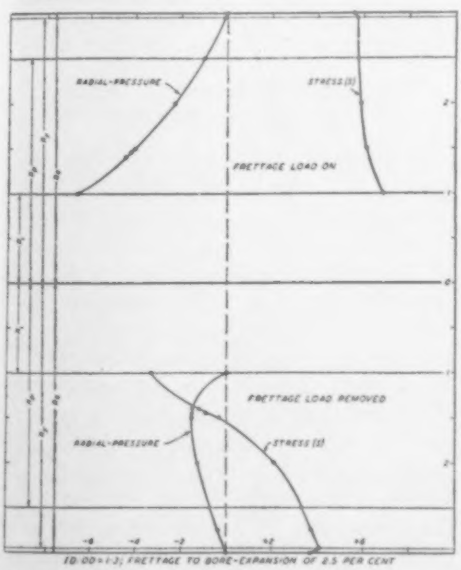


FIG. 5. STRESS DISTRIBUTIONS SET UP IN CYLINDER WALLS BY THE "AUTOFRETTAGING" PROCESS FOR HIGHER ELASTIC PROPERTIES IN PRESSURE VESSELS AND BIG GUNS.

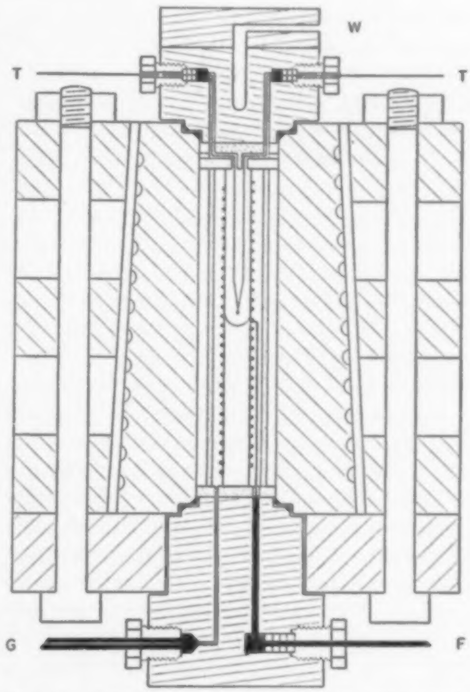


FIG. 6. CROSS-SECTION OF PRESSURE APPARATUS FOR WORK AT HIGH TEMPERATURES.

Operation with combined high temperatures and high pressures increases the practical difficulties enormously. For low temperature work the whole apparatus may be thermostated, but for high temperature work the walls of the steel vessel must be kept cool to retain their strength. Phase equilibria work has been carried out—in particular on silicate–water systems—to combined temperatures and pressures of 1,200° C. and 4,000 bars in an apparatus that was for a long time and may still be unique in the pressure field. Apparatus has also been designed for extending this high temperature work to pressures of 12,000 bars. A cross-section of such a high temperature-pressure apparatus is illustrated schematically by Fig. 6. It consists of a built-up cylinder capped at each end with lids. The provision for water-cooling channels as near the inner bore wall as feasible has resulted in a peculiar-

looking arrangement. Shrunk-on cylinders were used for a time but discarded for high temperature work because of the difficulty in correcting properly for the variable thermal gradients and other superimposed stresses in the walls. With this arrangement a fixed differential support may be obtained as indicated or varied at will by means of an additional hydraulic press similar to the device used by Bridgman for his coned cylinders. Electrically insulated electrodes are packed through the two lids. The lower ones feed current to a platinum-rhodium resistance furnace in the interior; the upper ones are thermocouples for measuring the temperature. The interior around the furnace is filled with reflection shields and thermal insulation material. The pressure medium is a gas fed in through the inlet "G."

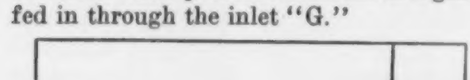


FIG. 7. CURVE OF ELASTIC COMPRESSIVE STRENGTH FOR IRON AT ABSOLUTE ZERO TEMPERATURE AS A FUNCTION OF HYDROSTATIC CONFINING PRESSURE COMPUTED FROM THE THEORETICAL MODEL OF GORANSON.

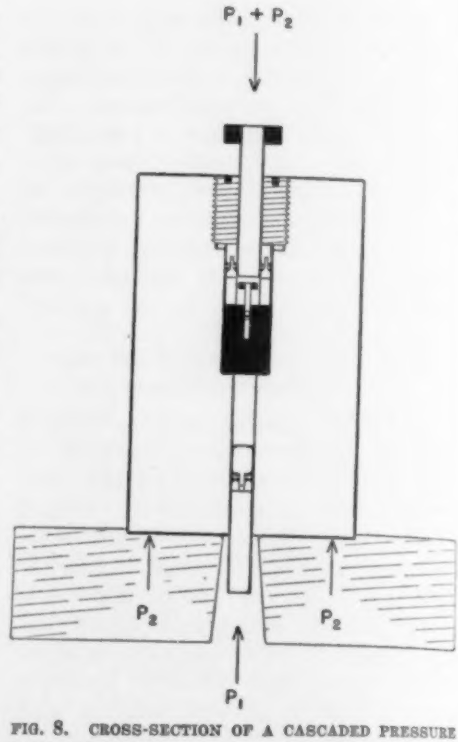


FIG. 8. CROSS-SECTION OF A CASCADED PRESSURE DEVICE CONSISTING OF ONE PRESSURE ASSEMBLY INSIDE ANOTHER. WITH IT PRESSURES TO 200,000 BARS HAVE BEEN BUILT UP IN THE INNER VESSEL.

Compressive Strength Under Hydrostatic Pressure

Pressure limitations of single stage apparatus will now be self evident. Many experimenters have undoubtedly contemplated the possible use of multiple-stage or cascaded pressure systems but have discarded the idea. The reason is very simple—any design based on an expected arithmetical increase in pressure per stage leads to such a bulky mutiplicity of stages that it would require an unlimited expense account to build the mechanism and a corps of people to assemble and operate it. It was not until the hypothesis of Goranson,[5] which predicted rapid increase of elastic compres-

[5] R. W. Goranson, *Jour. Chem. Physics*, 8: 323–334, 1940.

sive strength with increase in pressure of the surrounding medium, was sufficiently confirmed by experimental results, that construction of an apparatus based on such concepts was deemed worthy of consideration.

A curve of compressive strength as a function of hydrostatic confining pressure at zero degrees absolute computed for iron from this theory is plotted in Fig. 7. The interesting feature of this diagram is the shape of the curve which becomes infinitely steep at some finite value of confining pressure. This computation presupposes a perfect crystal, whereas in practice a solid will contain flaws, impurities and cracks, and may consist of a heterogeneous aggregate of crystalline grains. Under such conditions the first several thousand bars confining pressure will set up a non-uniform stress system by squeezing up on cracks and flaws in the structure. Consequently over this pressure region the increase in strength may be relatively small and perhaps even negligible. If the curve of Fig. 7 is modified to conform with certain assumptions made from these considerations it agrees closely with the experimental curves of David Griggs.[6]

The above discussion has reference only to the elastic strength but a solid may also fail by "plastic flow," a change-of-phase mechanism given by the free-energy relations mentioned earlier. The ease with which a material will flow under compression is, for constant test temperature, roughly proportional to the reciprocal of the absolute melting temperature. If, then, the confining pressure is high enough, a solid under compression can fail only by flow, and this condition sets an upper limit to the fundamental strength for temperatures above the absolute zero.

[6] David Griggs, *Jour. Geol.*, 44: 541–577, 1936; (with J. F. Bell) *Bull. Geol. Soc. Amer.*, 49: 1723–1746, 1938.

Apparatus for Work at Very High Pressures

A simple two-stage cascaded arrangement of pressure vessels is illustrated by Fig. 8. The first-stage pressure vessel has two pistons and pressure P_1 is developed in it by forcing up the lower piston. The first-stage pressure medium surrounds and acts on the exterior of the inner second-stage vessel and its piston. When the desired P_1 has been obtained the lower piston is kept fixed with respect to the upper piston. The outer pressure vessel is then lifted up against the upper piston which engages with and forces down the piston of the second-stage vessel. Since the upper piston and cylinder bore of the lower piston have the same diameter, P_1 remains constant during this latter operation. The pressure acting on the second-stage piston is equal to the ratio of first- and second-stage piston diameters squared and multiplied by P_2 less the friction.

Concluding Remarks

In this paper an attempt has been made to indicate, with some examples, what kinds of changes may be expected at higher pressures. Attention has also been called to the present limitations of theoretical physics in predicting very high pressure phenomena from low pressure measurements. Design of apparatus for very high pressure investigations has been discussed not only for its own sake but also because it illustrates the very interesting field of non-uniform pressure phenomena.

The writer has drawn freely from knowledge gained in his long, close association with Mr. L. H. Adams, director of the Geophysical Laboratory, and with Professor P. W. Bridgman, of Harvard University. He also wishes to express his appreciation to Mr. C. J. Ksanda, who prepared the diagrams for this paper.

THE STUDY OF HUMAN HEREDITY[1]

By Dr. LAURENCE H. SNYDER

PROFESSOR OF ZOOLOGY, THE OHIO STATE UNIVERSITY

One of the most interesting biological developments of the past decade has been the increasing realization of the importance of a knowledge of human heredity in everyday life. Of course a certain respect has been paid to heredity for a long time. The considerations given matters of birth, family background and race testify to this fact. It is only recently, however, that we have had any exact knowledge of the transmission of factors for diverse characteristics from generation to generation in human beings.

When the laws of heredity were discovered, tested and finally understood in experimental plants and animals, it was inevitable that the attention of the geneticist should be drawn to the study of similar phenomena in man. Gradually a body of knowledge on the genetics of man has been built up, and, as always happens when sufficient basic facts are accumulated, a series of practical applications has appeared.

The first of these practical applications involves the physician, who may find a knowledge of human heredity of value in diagnosis, especially early diagnosis. Instances are on record in the medical literature involving telangiectasis, polycythemia vera, spina bifida, orthoglycemic glycosuria, multiple exostoses and others, where the proper diagnosis was not made until the genetic background was taken into account. In the next paper in this series, Dr. Macklin will discuss this application in detail.

A second practical application of a knowledge of human heredity consists in the outlining of preventive measures as a result of the examination of the family history of the patient. Tests for preclinical and laboratory signs of a disease which has a genetic basis may be made in the relatives of affected individuals, and proper preventive measures instituted where indicated, before the condition becomes acute. This is being done by many physicians in cases of pernicious anemia and its antecedent achlorhydria, in certain types of cancer, in hemolytic icterus, in hypertension, in diabetes and in other cases where a genetic background is known.

A third practical application involves the lawyer. In recent years the heredity of several substances (antigens) found in human red blood cells has been carefully worked out. On the basis of this knowledge a man falsely accused in a paternity case may be cleared of the charge in certain instances. In a later paper of this series Dr. Wiener will discuss problems of this nature.

As a fourth practical application of a knowledge of human heredity, such knowledge may furnish the basis for advice on prospective marriages. It is a common experience for the geneticist to be asked "What are the chances that this trait which is in my family background will appear in my children?" Sometimes it is a trait which the individual may be desirous of having in his children, such as musical ability, intelligence or red hair. At other times it may be an unwanted trait such as feeble-mindedness, dementia praecox or deaf-mutism. When such questions are asked, the geneticist must call on his knowledge of the trait concerned, the possible genetic

[1] This is the first of a series of eight articles, each by a different author, on various aspects of human heredity. The general plans for this series of articles were prepared by Dr. Snyder at the request of the Editors.

basis, the variability caused by different environments, and from this composite picture reach some answer. Frequently the answer must be vague and unsatisfactory because there is not enough exact knowledge concerning the parts played by heredity and by environment in the production of the trait. Sometimes, however, where such knowledge is at hand, valuable information may be given.

In a recent case a hemophilic patient with a typical family history of the disease stated that his three daughters had not been told the nature of his affliction, nor were they to be told, since he was ashamed of the hereditary blemish, as he considered it. Yet if these daughters marry, half their sons will be expected to have hemophilia, a condition which proves fatal in childhood in the majority of instances. Advance knowledge of the chances of hemophilia in these families would at the very least make it possible for the mothers of sons to have everything in readiness for an emergency transfusion at any time.

In another case, a girl blind from aniridia was amazed to learn, upon consulting a geneticist, that half of her children of both sexes would be expected to have the abnormality.

Fifth, a knowledge of human heredity may furnish the basis for advice on prospective pregnancies. A young man recently came to us for advice on a family history of psoriasis, a skin disease. His father and grandfather had the disease, as did several brothers and sisters and some nieces and nephews. The young man's wife was then pregnant. After becoming pregnant she had learned of and seen the skin affliction of her husband's relatives, which, in the case of the girls and women, prevented the wearing of sleeveless or low-necked gowns. The young wife became obsessed with the idea that her child would have psoriasis. It preyed on her mind to such an extent that she was in danger of a nervous breakdown. Close examination of the family history revealed that in this family the psoriasis never appeared in a child unless one of the parents showed it. Only certain members of each family showed it, although all came in contact with it. It was apparently behaving as a dominant character. Since the young man in question was entirely free from the disease, it was possible to assure his wife that there was no danger of the child's inheriting the condition.

Sixth, a genetic knowledge can provide the necessary information for setting up eugenic and euthenic programs for the protection of society, a problem in which every citizen should be able to take an intelligent part, based upon experimental data, not on opinions, prejudices or the exaggeration of the uncertainties.

Seventh and last, there is every indication that with the discovery of more test factors of the sort exemplified by the blood agglutinogens, the taste deficiencies and others which can be determined in early childhood, we shall eventually be able to predict in children the probability of the occurrence of latent genetic diseases and abnormalities which may prove to be closely linked in inheritance with such test factors.

The various kinds of hereditary behavior now known are so complicated that their understanding requires a certain amount of study. This means that no one is justified in stating on his own responsibility that a given trait in man is or is not conditioned by hereditary factors unless: (1) He is thoroughly familiar with the known kinds of hereditary behavior. (2) He is familiar with the character under discussion in all its varying manifestations. (3) He has carefully investigated the character in a scientific manner from a genetic standpoint. This often involves the cooperation of geneticists, physicians, dentists and psychologists.

As in other sciences any hypothesis of

heredity, besides accounting for the facts at hand, must stand the acid test of predictive value.

In order to apply a knowledge of heredity to practical problems in human beings, certain fundamental conclusions must be granted. Among the conclusions taken for granted in the application of genetics to man are the following:

(1) The biological basis for the dozen or more major kinds of hereditary behavior has been adequately established by experimentation in animals and plants.

(2) Man fulfils the biologic requirements for being subject to the same laws of heredity as other organisms. (Among these requirements are sexual reproduction, a chromosome mechanism in which the chromosome number is reduced to half in the sperms and eggs, physiologic processes similar to those of other organisms, etc.)

(3) Hereditary factors are associated with the chromosomes. The evidence for this now amounts to what is practically a complete proof.

(4) Mental traits have their basis in physico-chemical structure, and are susceptible to the same laws of heredity as other characters. (Mental traits will be discussed in this series of papers by Dr. Penrose and Dr. Burks.)

(5) Heredity and environment are cooperative in the production of any finished character. One or the other influence may in certain circumstances appear negligible, but the dual nature may always be demonstrated.

Let us turn for a few moments to the principles involved in the analysis of human pedigrees.

The transmission of diverse hereditary factors from one generation to the next involves a series of phenomena resulting finally in the visible expression of characters in observable ratios. Most of the events in this series develop in direct consequence of the laws of probability, the probabilities being exactly determinable, thus making genetics more readily amenable to mathematical analysis at the present time than any other biological science. The included phenomena are as follows:

(1) *The segregation of factors into germ cells.* Segregation involves the separation of the two members of a pair of factors when germ cells are formed so that one member of the pair goes to one of the resulting cells, the other member to the other. Thus half the germ cells will normally contain one factor of the pair, half the other. If the two members of the pair of factors are different, so that the individual is said to be heterozygous for that pair, the germ cells will be of two sorts, in equal numbers, in regard to that pair of factors. Thus the probability that any given germ cell of a heterozygous individual will contain a particular factor is one half. However, abnormal segregation is known, in which certain factors do not separate from each other, thus changing in these instances the probability of a given germ cell containing a particular factor.

(2) *The assortment of factors during segregation.* If an individual is heterozygous for two or more pairs of factors, the factors segregate at random if they are located on different pairs of chromosomes. Thus, in regard to two pairs of factors, four kinds of germ cells will be produced in equal numbers; in regard to three pairs of factors, eight kinds in equal numbers, and so on. The chance of a given cell containing any two particular factors is therefore one fourth, any three particular factors, one eighth, and so on. However, if the factors are located on the same pair of chromosomes (in which case they are said to be linked) these probabilities are altered, roughly in proportion to the relative distance between the two pairs of factors on the chromosomes. This distance determines how often the factors may assort

at all, the assortment approaching a random one as the relative distance increases.

(3) *The type of mating.* When a population consists of various sorts of individuals, there will be, of course, various sorts of mating possible. The kinds and proportions of germ cells available for fertilization in any particular mating will depend upon the genetic composition of the individuals involved in the mating. Mass matings in a population may be at random or may be assortative (that is, certain types of mating tending to occur to the exclusion of others). The probabilities for various kinds of offspring depends among other things on the type of mating.

(4) *The frequencies, in the population, of the genes concerned.* The two members of a pair of factors may be equally distributed in a population, or one may be common and the other rare. The relative proportions can be determined by the use of certain mathematical technics, and are of importance wherever mass matings are concerned. Moreover, the frequencies of the two members of a pair of factors may have reached an equilibrium in the population, or they may not yet have done so. This too may be deduced by special methods. Gene frequencies and equilibria become of especial importance in the modern analysis of human pedigrees, and will be further discussed later in this paper as well as by Dr. Cotterman in a subsequent paper.

(5) *The union of the germ cells.* Fertilizations normally occur at random, that is, any sperm has an opportunity equal to that of any other sperm of fertilizing a particular egg; conversely, an egg has a probability equal to that of any other available egg of being fertilized by a particular sperm. Here again, however, exceptions occur, and cases of selective fertilization are known. In such cases the probabilities are of course shifted.

(6) *The interaction of factors, during development, with each other and with the environment, resulting in observable characters (phenotypes).* The characters finally produced and the proportions in which they are produced will depend upon this and the preceding five phenomena. These phenomena, serially taking place from generation to generation in specific environments, give rise to the phenotypic expressions of characters in definite ratios, from the analysis of which the laws of heredity have been deduced.

The type of inheritance involved in any particular case, the number of pairs of factors concerned, the mode of interaction and other relevant conclusions have long been determined from the study of the phenotypic ratios derived from specific types of mating. The classical genetic analyses of animals and plants have necessitated the scrutiny of at least three generations (parents, F_1 and F_2). Often additional generations (back-crosses, F_3, etc.) have been required. As long as such planned matings were readily made, there was no necessity of searching for other types of analysis. With the growing interest in the study of human inheritance, however, it was increasingly realized that the classic methods could not serve in this field. It became imperative to devise technics which would obviate the necessity of knowing the precise genotypes of the parents, and which would eliminate the need for the study of F_2 generations, back-crosses, etc.

Once the need was felt, the technics were not long in appearing. In general, such technics are based primarily on derivations of the frequencies of the genes in the population, the derivations being made from the frequencies of observable phenotypes. On the basis of such gene frequencies, the results of various mass matings may be predicted. The many methods now available have originated in scattered laboratories. Contri-

butions to this field have been made in England by Fisher, Haldane, Hogben, Penrose and others; in Germany by Bernstein, Lenz, Wellish and others; and in America by Burks, Wiener, Wright, Cotterman, Rife, Snyder and others. In the course of the development of methods for analyzing human inheritance the number of generations required for the analysis has been reduced first to two, and finally to but one, while the requisite knowledge of the precise genotypes of parents has been gradually reduced and finally eliminated entirely.

It must not be thought that methods which lessen the required number of generations available for study or which minimize precise genotypic knowledge concerning parents are more desirable or more efficient than the classic methods. It is merely that they must serve, as efficiently as possible, in a field in which test matings of precisely known genotypes are not available.

It will be readily seen that no single method can answer all the questions about the genetic bases of human characteristics. Various technics are concerned in solving the problems as to the number of pairs of factors involved, whether these factors are acting as dominant, recessive, blending, sex-linked, sex-influenced, lethal or multiple factors, whether or not epistatic relationships are present, and whether the factors are linked or independent. In predicting the proportions of different types of offspring to be expected from various mass matings involving specific phenotypes, complications arise in that a single phenotype often includes several different genotypes. In linkage studies a heterozygous genotype may include both coupling and repulsion phases. Hence it is necessary to provide suitable statistical corrections and allowances, since in human data such complications can hardly be avoided. The philosophy of the mathematical approach to the study of human inheritance will be presented by Dr. Cotterman in a subsequent paper.

One of the points most frequently overlooked in the study of human heredity is the matter of equilibrium in gene frequencies. It should now be a commonplace that equilibrium in regard to the genotypes resulting from a pair of autosomal factors exists when the homozygotes for one allele, the heterozygotes and the homozygotes for the other allele are in the relative proportions p^2, $2pq$ and q^2, respectively, where p and q are the frequencies of the two alleles so that $p + q = 1$ and p or q may have any correlative value from 0 to 1. Moreover, if anything occurs to displace the equilibrium, a new equilibrium is reached after a single generation of random mating. For sex-linked genes, epistatic interactions and other complicated cases, equilibrium may be reached more slowly.

Self-evident as these propositions would appear to be, misunderstandings of them and of their implications are all too frequent in discussions of human heredity. It is often said, for example, that a dominant character increases in the general population at the expense of its recessive counterpart until it stands in the ratio of 3 : 1. This statement has no basis in fact. A recent text states that "albinism is due to a recessive factor, *which explains why it is so rare*" (italics mine). Another book, a treatise on handedness, proclaims that "left-handedness occurs in 25 per cent. of the population, *which indicates that it is a Mendelian recessive*" (italics mine). Each of these statements shows a complete lack of understanding of the principles of equilibrium.

A recessive character may be common or rare in a population, depending upon the relative abundance or scarcity of the hereditary factor determining the character. Split hand, or "lobster claw," in which the hand has only two large fingers, is due to a dominant factor, the

normal complement of five fingers being due to its recessive allele, yet the recessive character is the common condition. Recessive characters may occur in various populations in any frequency whatsoever from 0 to 100 per cent.

A recent prize-winning essay of the Eugenics Research Association contains this remarkable pronouncement: "We are indeed lucky that the mental disorders or psychoses are not dominant traits, or we would all be insane by now, according to the laws of heredity." In a recent manuscript on finger-prints which I was requested to read and criticize appeared the following paragraph:

> Here we have a pattern (arches) which when crossed with another of the same classification, produces its own kind, plus loops and whorls. This reaction seemed to fit the requirements of a character heterozygous in the parents and segregating in the 1: 2: 1 ratio. A check on the frequency of arches in the general population quickly invalidated such a supposition, however, for it was found that only about 5 per cent. of all patterns are arches. Support for such an idea would require 25 per cent. loops, 50 per cent. arches and 25 per cent. whorls. Some other explanation was therefore necessary.

Here again we have examples of complete misunderstanding of gene frequencies and equilibria.

I have belabored this point because the lack of attention paid to these important considerations has greatly retarded the progress of the study of human genetics. The necessity for a thorough understanding of the unique problems involved in the genetics of man must be appreciated before further progress can be made. Some attempt at creating such an understanding will be made in this series of articles.

Among the problems facing the student of heredity in man, many of which will be considered in detail in later papers of this series, are the following: to test the linkage relations of known human genes and to construct maps of the human chromosomes by the use of the newly elaborated paired-sib technic; to search actively for new genes in man; to further elaborate the gene-frequency technics and other statistical methods for the analysis of hereditary human factors; to determine the phenotypic frequency of various traits in the population—in other words to take a census of human traits; to establish and maintain twin clinics in qualified hospitals; to study intensively the genetic and environmental influences interacting in the production of "mental" characters; to obtain relevant facts about the genetic and environmental backgrounds of socially significant traits of all sorts; and finally to create an awareness of the importance of the genetic viewpoint among physicians, social workers and the general public.

It is the hope of the student of human genetics that such a cooperative line of research may eventually give rise to a social edifice, the foundation of which is made up of substantiated facts about the development, both from a genetic and an environment standpoint, of human characteristics, and the superstructure of which is a tower of eugenic strength which can be defended against any attack. To this end we bespeak the cooperation of biologists, physicians, anthropologists, psychologists, sociologists, legislators and social workers, and we ask the continued faith and support of the public.

GERMINATION OF SEEDS

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EVERY one who has had experience in the germination of seeds has encountered difficulties at one time or another. If the seeds possess a dormant embryo, as is the case for many of our temperate zone plants, especially trees and shrubs, there is a very definite and simple procedure which may be used to bring about germination. If, on the other hand, the embryos are not dormant, but the seeds still fail to germinate under ordinary conditions, some other special treatment must be given. Some of these peculiarities are exhibited by our very common seeds.

Certain specific temperature conditions are necessary for the germination of many forms. For example, wild columbine seeds germinate very poorly at a constant temperature as high as 77° F., but give excellent germination if the daily temperature alternates between 59° and 77° F. Annual delphinium or larkspur seeds show very poor seedling production at temperatures above 58° F. but can be induced to germinate at temperatures as high as 86° F. by pre-treatment on a moist medium for one, two or three weeks at temperatures of about 50° or 59° F. Lettuce seeds can also be made to germinate at high temperatures normally inhibitive by pre-treatment for four days in a moist condition at 41° F.

The difficulties encountered by many rock garden enthusiasts in the germination of seeds may be attributed to any one of several factors. Seeds of *Primula obconica* and *Ramondia pyrenaica* require light for germination. Although light is not essential for the germination of seeds of *Draba aizoides*, *Gentiana lagodechiana*, *Mimulus langsdorfii* and *Primula denticulata*, exposure of all these seeds to light during the germination process permits seedling production at temperatures ordinarily inhibitive. Other rock garden plants, such as *Calochortus macrocarpus*, *Camassia leichtlinii* and *Lewisia rediviva*, germinate only at low temperatures of approximately 41° F. Still another group of rock garden plants, including *Draba alpina*, *Meconopsis cambrica* and *Gentiana crinita*, possess dormant embryos and must be pre-treated at low temperature, after which germination proceeds at ordinary greenhouse temperatures.

Many weed seeds not only show a delay in germination but are capable of distributing their seedling production over a period of years. This fact is demonstrated repeatedly by the years of cultivation necessary to get rid of weeds in a garden plot, even if care is taken to eradicate all weeds as they appear and to prevent the introduction of new weed seeds. The soil contains many dormant seeds which produce plants promptly when cultivation, excavation or erosion gives them the moisture, temperature and oxygen supply or the exposure to light required for germination.

The survival advantage to the plant of delay in germination, due to specific requirements, is further demonstrated by the behavior of the seeds of certain winter anuals growing in desert regions. The germination of these seeds immediately after harvest, when the seedlings could not survive because of the heat, is prevented by the requirement of comparatively low temperatures, or combinations of low with moderately high temperatures, for germination. An additional protection is the dormancy exhibited by freshly harvested seeds of these forms. This dormancy disappears

by the second summer rainy season when the seeds germinate and the seedlings grow.

Dormancy in freshly harvested seeds is also prevalent in some of our common cereals such as wheat, barley, rye and oats. This is an advantage to the farmer in that there is no loss of grain due to germination in the shock. Seed-testing stations, on the other hand, find this character a decided problem in testing cereal seeds for germination capacity, since at the temperatures normally used for tests, only the non-dormant seeds germinate. They have found, however, that all the viable seeds, both dormant and non-dormant, will germinate at approximately 50° F., so that a good index of the real germination capacity can be obtained at this temperature. Similarly, testing laboratories have used daily alternations of temperature as well as light to determine the germination value of seeds of some of the grasses of meadow and pasture.

Still other seeds fail to germinate because of hard coats which prevent the absorption of water. These seeds are especially common in the legume family. Sweet clover, alfalfa, wistaria and locust are some of the forms which produce hard-coated seeds. Several methods have been developed for making these coats permeable and thus bringing about germination. Among these are hot water or sulfuric acid treatments, filing and passing the seeds through abrading machines. The last method permits the treatment of large quantities of seeds.

The seeds of varied and numerous temperate zone plants possess dormant embryos. One of the best-known methods for bringing about their germination is that of low temperature pretreatment, generally known as "stratification." This process consists in placing the seeds in some moist medium, such as granulated peat moss, sand or soil, and placing them at 33°, 41° or 50° F. for certain periods of time. From one to several months in this condition is required for after-ripening the seed. At the end of the low-temperature or after-ripening period, the seeds will produce seedlings promptly in the greenhouse. In nature, the winter supplies the low-temperature period, so that, if the seeds are moist, they are after-ripened and prepared for germination the following spring. Seeds of water plants as well as those of land plants are affected. Water plantain, wild rice, bulrush, fringed gentian, wintergreen, bittersweet, flowering dogwood, spruce, pine, bayberry and roses are among those plants having seeds which respond to stratification at low temperature.

An increasing number of seeds are being found to possess both hard or resistant coats and dormant or partially dormant embryos. To remove the inhibition of germination in these cases, it is necessary first to remove the coat effect and then pre-treat at low temperature in order to after-ripen the embryo. Seeds of this type, if planted in a moist medium at a warm temperature (68° to 86° F.), will be attacked by bacteria and fungi which cause the partial degeneration of the hard coats. The length of time necessary for this action has been found to vary from 30 to 120 days, depending on the species. At the end of this period, a transfer of the culture to low temperature will after-ripen the dormant embryo, after which germination will proceed at ordinary greenhouse temperatures. The coat restriction may also be removed by any of the treatments described above for hard-coated seeds. Some of the seeds requiring this treatment are bearberry, snowberry, basswood and certain species of cotoneasters and hawthorns. Such seeds can be handled practically by planting in the spring or early summer in a temperate climate. The coats will deteriorate dur-

ing the summer, the embryos after-ripen during the winter and the seedlings appear the following spring.

Certain seeds produce a root readily when exposed to ordinary temperatures for germination, but they fail to produce shoots if kept continuously at those temperatures. Here, it is necessary to expose the germinated seed, with the root system beginning to develop, to low temperature (33° to 50° F.) for a while in order to after-ripen the epicotyl or the bud that forms it. A number of the "two-year" lilies, the tree peony and the high bush cranberries exhibit this type of dormancy. All seeds of this type have been known as "two-year" seeds. However, they can be made to produce seedlings the spring after harvest by planting them in flats in a greenhouse, where they should be allowed to remain until root systems are formed. The flats should then be transferred to low temperatures for one-half to four months, depending on the species. Practically, these seedlings may be produced in the same way as those in the preceding category, that is, by spring or early summer planting. For example, seeds of *Lilium auratum* planted outside in April or June in the region of Yonkers, N. Y., gave good seedling stands the following spring. The warm months during the summer permitted the emergence of the radicles and the development of the root systems, while the succeeding cold of the winter months broke the epicotyl dormancy. Plantings made as late as August produced very few seedlings the following spring, since the warm period was too short to permit root formation. The flats were kept in a board-covered frame over winter.

Many of the seeds which are favorably affected by low temperature pre-treatment exhibit a partial dormancy of the embryo. When these embryos are removed from the coats and placed in germinators, they grow very slowly and the tops produced by such seedlings are dwarfed. Artificial dormancy is thus induced. This condition has been reported for the Japanese rose tree, peach, apple and hawthorn, all of which belong to the rose family. If grown at 62° F. or above, they remain dwarfs for six months to a year and a half, after which one or more buds start to grow. On the other hand, if, at any time, the dwarfs are exposed to 41° F. or lower for two months, the secondary dormancy is overcome and vigorous growth follows promptly upon removal to a higher temperature.

Seeds with dormant embryos have contributed their share to the problems of seed-testing laboratories. If the germination methods described above, including months in stratification at low temperature, are used, the viability may be obtained. In many cases, however, it is desirable to know quickly whether a certain seed lot is worth purchasing or planting. As a result, many methods for rapid testing have been devised. One of the most successful of these consists in removing embryos and placing them on moist filter paper in Petri dishes. Within a week or two, the live embryos enlarge and, in light, become green, while the dead ones become brown and decay.

Although many of the problems in seed germination have been solved, new ones are being encountered daily by seedsmen, gardeners, florists, conservationists and others to challenge the workers in this field.

FREE ENTERPRISE AND SCIENTIFIC DEVELOPMENT

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THE phrase "free enterprise" is commonly used to designate the system of economic organization that has flourished from the early nineteenth century until recent years in the most prosperous and progressive nations. This system has many other names. Adam Smith called it the "system of natural liberty," although when he wrote it did not exist except in the imagination of thinkers like himself. It has been called, in praise or dispraise, the system of *laissez-faire*. Other names, referring to parts of the system rather than to the whole, are "the competitive system" and the "price-system," or sometimes merely "capitalism." Whatever its proper designation, it is admitted by friends and foes to have been responsible for, or at least to have permitted, a more rapid increase in the productive efficiency of the human race and in the standard of living of the common man than has been recorded in any previous period of equal duration.

At first sight this seems strange, for the outstanding feature of the system is that it is not based on any one's conscious desire to serve the social interest or to raise the standard of living of any one but himself and his family. How has it worked to bring about this result?

The essential details of the system of free enterprise are: (1) that every individual is permitted to use his own resources and those voluntarily entrusted to him by other individuals to produce goods or services; (2) that these goods or services are offered for sale in competition with other goods or services; (3) that customers indicate their preference and the relative intensity of their wants by the price they are willing to pay for each product; (4) that the producers who have successfully gauged the customers' demand and are able to produce at a cost less than the price they can obtain, make money and, in consequence, increase their output, while other producers lose money and are compelled to reduce their output or improve their methods. What and how much shall be produced is determined by the way the public spends its money. Who and how many shall produce are determined by the number of persons with sufficient skill, capital and daring to produce at a price low enough to give them a share of the market. What price shall be charged is determined within limits which are usually very close, the lower limit being set by the cost of production of the least efficient producers whose supply is necessary to satisfy the demand, and the upper limit, which is rarely reached, being set by the price of some substitute object of expenditure. It will be observed that there is in this scheme no place for an authority to determine who shall produce what or what price shall be charged. There is no compulsion—only persuasion. Prices are the governor of the free enterprise system.

The alternative to the system of free enterprise is what is known as "planned economy." Free enterprise is, of course, a plan for the economy, a plan for decentralization and individual responsibility. However, as the phrase "planned economy" is commonly used it means the direction of all or a large part of the economic activities of the nation by the

government or by some organization controlled by the government and endowed with quasi-governmental powers. Since any body that controlled the economic activities of a nation, and had, in addition, the powers already possessed by government, would be able to control the total of human activities, planned economy as outlined by its leading advocates is merely a modification of totalitarianism, phrased in language not so shocking to the ears of free men as the language of Communism and Fascism.

The system of free enterprise resembles the political system that we have known as democracy in that it is based on persuasion. The purchaser is the voter who determines who shall produce and his vote is influenced by advertising as well as by recollections of previous services rendered. But producers have no power to coerce the public, whereas politicians once elected do have that power. As long as the politicians are limited in the scope of their activities their coercive power may be beneficial. We do not mind coercing criminals; we do not even object to coercing taxpayers if the taxes are spent for purposes generally approved, and without excessive waste. But if politicians were given the right to produce goods or to regulate in detail the activities of producers, their power would be enormously increased. We should have substituted coercion for persuasion in the production and distribution of goods. That in turn would strengthen the power of the politicians in the fields they already controlled. The constitutional and customary barriers protecting minorities would be broken down. Because of the apparently greater efficiency of a single executive the rights and duties of the legislative body would be forgotten. The forms of democracy might be preserved but the substance would be gone. Students of ancient history are well aware that the senate and consuls of Rome were regularly elected and went through the motions of legislation and administration for 300 years after Augustus established the Empire, while, officially the Emperor was only the commander of the army, the ruler of certain provinces and the leading citizen of Rome.

The totalitarian or authoritarian systems have varied considerably in their political structure. Some have been absolute monarchies based on a claim of divine right. Some have been oligarchies, some theocracies, some, ostensibly, democracies. Nearly all have claimed to be acting in the interests of the whole people. In fact, it would be almost impossible to find a dictator who did not claim to be the true friend of the people and who did not try to prove that friendship by conspicuous acts of generosity, frequently at the expense of his political opponents. But real democracies—unless the term is used as synonymous with the tyranny of a demagogue—are inconsistent with governments of unlimited powers. The rights of minorities, the liberty of individuals to control their own activities within wide limits, freedom of speech and of the press—in other words, all that has made what we know as democracy dear to the hearts of Americans— can not be maintained under a government that asserts broad powers over economic activities. In the name of efficiency, all opposition to the plans of the government must be suppressed, and it is an easy and inevitable step to suppress those varieties of scientific and religious thought that meet with the disapproval of the dictator, even if they are not directly and closely connected with economic activities. The hand of the state will reach all the corners of society, and all research will be devoted to proving that the government is right and its critics are wrong. After a short time that job will be easy, for the only critics left alive will be foreigners.

Lord Acton once remarked that "All

power corrupts, and absolute power corrupts absolutely." If the word "corrupt" is used in the narrow sense of financial corruption or corruption of personal morals, that is not always true. But power does corrupt judgment and respect for the opinions and rights of others. It removes men from the opportunity of discussing matters with their equals and causes them to be surrounded by special pleaders, sycophants and yes-men. Even when the facts can not be concealed or overlooked, power leads men to adopt the dangerous doctrine that the end justifies the means, and to do evil that good may result. And if sometimes we find that the evil they do is done to those whom they hate, and the good resulting results to their own benefit, that is only natural and comparatively unimportant.

It was a recognition of the dangers of concentrated power that caused our forefathers to set up a form of government in which the powers of government were narrowly limited and subdivided, under which the system of free enterprise was possible. Their wisdom can be tested by observation of the results attained.

One might expect that under the system of free enterprise the business men would have waxed wealthy at the expense of wage-earners and consumers in general. Such has not been the case. Competition among business men has compelled them to bid against each other for laborers, by raising money wages, and to bid against each other for customers, by lowering prices or improving quality, thus increasing the purchasing power of wages and all other kinds of income.

The last statement may be challenged, because prices have been quoted in money that has from time to time undergone sudden changes in purchasing power, either as a result of credit inflations or the debasement of the currency by politicians. But if we compare the price of an hour of common labor, or the price of a representative group of farm products, with the prices of manufactured articles over a period of years there can be no doubt that manufactured articles on the whole have fallen very greatly in price since the industrial revolution, and that that fall has been almost continuous except during great wars. Farm products have fallen by comparison with labor, but not so much as industrial products, because the necessity of using inferior or more distant soils to supply the needs of an increasing population has partly offset the improvements in farm machines and methods. Farm products therefore rose fairly steadily in price by comparison with industrial products until 1929, although they fell more rapidly during the depression. The cost of living, which is composed of both farm and industrial products, plus a large amount of services, has also fallen greatly by comparison with either hourly wages or weekly earnings. At the same time, rates of profits on invested capital and rates of interest on loaned capital have had a generally downward trend during most of the last century. These facts taken together constitute proof that the system of free enterprise has resulted not only in increasing the national income but in spreading the increase widely among the people.

There has been a good deal of criticism directed against this system, most of which stems from the teachings of Karl Marx, although many of the critics are not consciously followers of Marx. Marx's theories were evolved at a time when the free enterprise system was just getting started. They were based largely on Ricardo's iron law of wages, which economists since Ricardo have completely discarded. His illustrations of the poverty of the workers and the arduousness of their tasks were drawn from conditions of a hundred years ago. At that time, although the condition of most of

the poor was better than it had been under the older system of planned economy, it was very much worse than now. Since Marx's time inequalities between rich and poor have diminished, and all classes have become much more prosperous.

Other criticisms not directly derived from Marx's teaching are based on misunderstandings of the classical economic theory or ignorance as to conditions prevailing when that theory was formulated. There is much talk of the breakdown of competition, although competition was never more effective in its task of supplying consumers with a large variety of articles at low prices than it was in the 1920's. (When I say low prices, I mean, of course, low in comparison with consumers' incomes.) There is much talk of rigid prices, although the statistics show plainly that the prices of manufactured goods were more rigid a century ago than now. A considerable degree of rigidity is and always has been inherent in the prices of goods produced with rigid costs, and the cost of hired labor, which is the chief element in the cost of most manufactured goods, has always been rather rigid—more so in recent years because of the activities of the government and the labor unions. There is much talk of monopoly, based on the naive assumption that every large concern must be a monopoly. There is much talk about the concentration of control over industry in the hands of 200 corporations or 60 families, although the statistics when properly analyzed show no evidence of a trend toward increasing concentration of either industrial production or individual income. Even if the control of industry should become concentrated in the hands of a few hundred families or corporate groups, and even if these groups should attempt to work together, no longer competing, they would still be unable to tax or fine or imprison their customers and would-be competitors as the government can do, and they would still be subject to taxation and such other measures of government control as might be necessary to protect the public.

Since the system of free enterprise is based on the desire of each person to make as large an income for himself as possible, within the limits set by his ability, opportunity and desire to work, it follows that any line of enterprise that promises or is showing large profits will attract competing enterprises unless it is protected by law or by some natural peculiarity. There are some natural monopolies, such as the local supply of light and power and some forms of transportation, where competition would result in waste and poorer service to the public. There are also some natural resources so located and so valuable that if controlled by a monopoly the price of their products could be raised to a point that would result in excessive and undeserved profits. It is necessary also to mention that the activities of banks of deposit are so vital, and the possibilities of damage to society so great if they are not properly performed, that they have always been regulated by law to a greater extent than ordinary businesses. Cases like this are exceptional, and I think no economist would deny that they require special treatment. Whether that special treatment shall consist of government ownership, or rate regulation, or discriminatory taxation, or attempts to enforce competition, is a matter that must be decided according to the circumstances of each case. Whatever treatment is adopted will have its disadvantages, among the greatest of which will be the power it gives to politicians to favor certain groups of voters at the expense of others.

Although all competent students of economic history, including intelligent radicals, have been compelled to admit that the system of free enterprise has

greatly increased the production of wealth and the purchasing power of the common people, the public does not seem to be aware of the extent of that increase or the great contrast it makes with the history of preceding centuries.

Now it happens that there exists a record of a number of retail prices of goods and clothing, and a number of typical wage-rates as they were established by law in the reign of the Roman Emperor Diocletian. Professor Frank Abbott, of Princeton, constructed from these prices and wage-rates a table of workingmen's purchasing power in 300 A.D. for comparison with a similar table for 1909 A.D. According to his study, the purchasing power of artisans had increased about threefold in 1,600 years. But for our purpose it is more important to note that none of the improvement took place before 1800. If there were any gains in the interim they were lost, and there is no record of any such gains, although there were periods when the standard of living rose from the lowest depths for a time, especially after 1349 and after 1600.

The records of prices paid for food, clothing and fuel by hospitals and other public institutions in London, combined with daily rates of wages, show, according to my calculation, that the purchasing power of artisans in London increased 228 per cent. from 1800 to 1932. Professors Warren and Pearson calculated an increase of 680 per cent. for the same period.

Studies of the earnings of industrial laborers in the United States and the cost of living have been published by various economists. They show an increase in real wages between 1798 and 1932 of between 226 per cent. and 1220 per cent. My own estimate is 291 per cent. In other words, the average workingman can buy about four times as much with his wages as he could 140 years ago, while working only two thirds as many hours. None of these studies makes any allowance for the value of free schooling, or public health and recreation facilities not formerly available to laborers.

I have mentioned several times improvements in methods of production or quality of product. That is where the application of scientific discoveries comes in. A sound economic system must encourage the application of scientific truths to human welfare. Most present-day industrial processes would be impossible without the scientific inventions of the last century. The business men who have guided industry under the system of free enterprise have made great use of the work of scientists. They have continually experimented with new ways to satisfy the public's wants. There may, of course, be a question whether under some other system of economic organization the work of scientists might not have been utilized as much or even more. That question can not be answered by the simple experimental methods available to some branches of natural science. Economics deals with human beings, their habits, tastes and aspirations. Experiments involving human beings are costly and dangerous. Moreover, it is unusually difficult in such experiments to isolate the subjects and practically impossible to establish controls or to repeat experiments with slight variations. An important experiment affecting a whole nation, even if its failure is evident, can not be undone, and may make a return to former and better ways impossible, to say nothing of the expense and suffering it may cause.

We have been unusually fortunate in this country in having forty-eight distinct state laboratories, and many thousands of distinct industrial laboratories so that economic experiments on a small scale have been possible. It is strange indeed that the school of political thought that is most enthusiastic for the experi-

mental method in political economy is strongly committed to breaking down the walls between these laboratories, and is willing to gamble the fate of a whole nation on each new venture.

Generally speaking, however, economics must progress without the benefit of laboratory experiments except of a minor kind, and must rely on the scanty material afforded by history and contemporary international comparisons. But because the material is scanty is no reason why it should be neglected. Let us therefore examine the relation between science and the economic system in some other times and places.

Pure or abstract science has flourished under widely different forms of political organization. It requires a comfortable standard of living for the persons immediately engaged in it, and a strong enough government to protect them and their property from violent attacks, but does not require that the general standard of living shall be high. The social milieu, however, has a pervasive effect on scientific thought and even the abstractions of metaphysicians show traces of their origin.

Anarchy is inconsistent with learning. On the other hand, too much security, or, rather, too little change in the outside world, seems to be inconsistent with the development of new ideas. Under stable conditions of society learning tends to develop into pedantry and traditionalism frustrates originality. That is especially true when there is no pecuniary incentive to apply scientific principles to the ordinary affairs of life. The great advances in pure science seem to have taken place in the generations following a period in which different civilizations have come into contact, and to be a result of the impact of conflicting ideas on bright minds—for example, the development of Greek thought after the Persian wars and the conquests of Alexander, and the continuation of that development under Roman auspices until the Romans ceased their territorial expansion. That period was also marked by great commercial activity. Another period was the thirteenth century, following the crusades. Of course the fifteenth century renaissance was based partly on the transfer of Byzantine learning to the West and partly on new discoveries in Africa, America and Asia. Most of those discoveries were made by adventurers seeking for profits. Apparently the contact between different nations, languages and religions has been sufficient since then to keep the scientific current flowing almost continuously in nations of all degrees of political freedom and economic well-being. A large part of that contact has resulted from the efforts of traders and investors to make money for themselves.

It is not my intention to belittle pure science. The pursuit of knowledge for its own end may have some other justification, but whether that is so or not it seems to be essential for substantial improvements in the application of science. Some brilliant and profound thinkers are so constituted that they can work best without thought of the practical value of their work, while others with different habits of thought can only work when they see a hope of tangible reward. However, economists are naturally most interested in the applications of science, and are inclined to measure scientific progress by its results on the welfare of mankind, and must, therefore, look with disfavor on a social structure that permits the application of scientific discoveries to be delayed or devoted to undesirable ends.

Authoritarian or totalitarian states have usually permitted abstract speculation, provided it did not result in conclusions that were inconsistent with the shibboleths of the ruling caste. They have even at times permitted limited groups of scholars to hold heretical

opinions provided such opinions were not made known to the masses. Certain sciences and arts that would not conflict with the interests of the rulers were permitted and encouraged.

Mathematics, physics, astronomy, music, painting and architecture have flourished under dictatorships. But they have not been free. Everyone knows of Galileo's experience. As long as the church dominated society and was able to enforce its decrees, the shadow of Aristotle lay across the field of science, stunting growth. More recently in Germany we find achievements of science and works of art condemned and destroyed merely because of their author's race.

In a totalitarian state the possible applications of science are limited by the imaginations of the ruling class and the custodians of the sacred tradition. In a society dominated by a military caste, inventions that can be used for destructive purposes may be encouraged, although professional military men are notoriously conservative, and little original work has been done by military authorities even in the field of their special interest. Most military and naval inventions have been the work of laymen except in matters of detail. Many have met with opposition from military authorities until the stress of actual war compelled their adoption.

It is not recorded that Archimedes' speculations in physics were either aided or hindered by the tyrants of Syracuse, although they were glad to use the artillery he invented. Gunpowder was discovered in both Europe and China at a time when business was looked down upon. The Chinese, being religious rather than warlike, used it to make firecrackers for festivals; the Europeans used it for guns; only much later did private business men develop its uses for mining, roadmaking, and stump removal.

Governmental authorities are sometimes ridiculously reactionary and often they are inclined to schemes that are more spectacular than useful. These tendencies are illustrated by the immense sums of taxpayers' money spent in building barge-canals after railroads and automobiles had made them obsolete; in developing stupendous hydro-electric plants to supply markets where coal-power would be cheaper; in constructing flood-control projects so elaborate that the annual interest on the money invested is greater than the average annual loss from floods in the area to be protected; in building model villages of houses too expensive for the incomes of the persons they were intended to serve, or too far from their places of work, instead of remodeling existing structures; in teaching handicrafts whose products can not compete with machine-made goods; in subsidizing non-essential industries that can not compete with foreign products; in planting trees over large areas where lack of rain has never permitted trees to grow.

The positive acts of repression performed by authoritative states have probably not been as harmful as their removal of incentives to progress along lines beneficial to individual human beings. Restrictions on the operations of the profit motive have made it difficult to finance inventions, adopt technological improvements or produce new varieties of goods that could be sold to the people. It has been said that necessity is the mother of invention. Perhaps it would be more correct to say that ingenuity is the mother of invention. But whoever is the mother, if the invention has economic value, the business man looking for profit is usually the midwife. However, if the invention is one that is expected to aggrandize the ruling class and help suppress opposition, the totalitarian state will delegate innumerable bureaucrats to assist at the *accouchement* and claim credit for the conception as well.

The outstanding peculiarity of the sys-

tem of free enterprise has been that the initiative in both scientific work and production has been taken by individuals working for their own reasons and not at the direction of rulers or political or religious bodies. Moreover, in carrying out their projects they have been comparatively free from restrictions, except those based on public health and safety, as long as they operated honestly and without fraud or violence. The motives for activity have therefore been different from those effective in "planned" society; the human qualities required and the rewards expected have differed in degree and importance, if not in kind. These differences have extended to the common people as well as to the leaders.

The instincts or proclivities leading to business or scientific activity have been variously catalogued by writers on the subject. It is not necessary for our purposes to delve into psychoanalysis or to worry about the physiological bases of psychological phenomena or to quarrel about the definition of an instinct. All we need to consider is the effect of certain social, political and economic institutions on the operation of certain tendencies present in human beings and causing them to act as scientists or as economic men. The leading instincts directing human activity in science or business may be stated as folows:

(1) Curiosity or ratiocination.
(2) Contrivance, construction or workmanship.
(3) Emulation or imitation.
(4) Devotion, sympathy or altruism.
(5) Domination or love of power.
(6) Acquisition, accumulation, collection or ownership.

I have omitted the family instinct and the instinct of self-preservation because they are so general in their nature that they can not be said to direct men's activity into one line rather than another, except that they may tend to stifle originality in societies where everyone is expected to conform.

Recognizing that most actions are undertaken for mixed motives it is yet obvious that the first four of these instincts are especially important in connection with pure science, while the last five are especially important in connection with applied science and in connection with business enterprise. The last instinct named, that of acquisition, is not always powerful in the make-up of inventors, but there have been many inventors who were plainly under its influence. Some of the instincts in this list are also responsible for activities that can not be classified as either scientific or economic, such as the pursuit of military glory, politics, sports or religion. It should be recognized also that most men are not conscious of their motives, or even deceive themselves with regard to them. Actions based on fundamentally different motives may be outwardly similar, and actions based on essentially similar motives may be very unlike, and there is little connection between the purity of a man's motives and the social value of his actions.

All this may be freely admitted, yet it remains true that the social environment determines which instincts shall find freest expression, and especially how they shall be expressed. And it is worth while noting that the instincts that lead to business activity are similar to those that lead to the study of applied science. Consequently, an environment that encourages business activity tends to encourage the application of scientific discoveries to profitable ends.

Scientific progress has affected the economic structure of society in many ways. These, however, can be classified under four main heads: (1) Labor-saving devices; (2) transportation improvements; (3) new objects of consumption; (4) improvements in quality or lowering the price of objects of consumption already known. And in each one of these divisions not only has science affected the economic structure of society, but the

economic structure of society has limited and directed the application of science.

(1) Labor-saving devices include the elementary physical machines, the application of animal power and, above all, the application of power derived from gravity, heat or electricity. The object of these devices is to economize human labor, to enable more work to be done with a given number of workers, or the same amount of work to be done with less effort.

There was little application of power for industrial purposes under the ancient totalitarian states. Grist-mills run by water developed rather late and the uses of water power for irrigation were very limited. The principles of the steam engine were worked out by Hero of Alexandria, but it was used only as a toy or for the purpose of opening temple doors. Hero also invented a vending-machine which was used for dispensing holy water, and a combination automobile and puppet-show that was used for public entertainments. None of these inventions was widely used or had any effect in improving the condition of the people.

Hero, Archimedes and several other scholars of ancient times also invented several varieties of military machines that did come into general use. The political authorities were willing to use tools of defense or aggression; the religious authorities were willing to use devices to impress the populace; but neither group was interested in lightening the tasks of the workers or in increasing their standards of living. Totalitarian states, in fact, have always aimed at increasing the numbers of their subjects rather than their standards of living. They have wanted cannon-fodder, or its equivalent in the pre-gunpowder days, and one of the two most easily handled types of cannon-fodder is the type of man who can be persuaded that the glory of the group is worth more than the well-being of the citizen. The other is, of course, the type that is willing to exchange his life for the promise of eternal bliss in the hereafter. Both types are commoner among those who see little hope for advancement in this world through their own efforts.

(2) Cheap transportation is essential for large-scale production, and large-scale production is essential for the most efficient division of labor. But the benefits of cheap transportation resulting from scientific discoveries are nullified by tariff and similar barriers imposed by totalitarian states as part of their economic planning. It must be acknowledged that free states have also erected barriers to international trade and that such barriers have reached unprecedented heights in recent years. But autarchy or national self-sufficiency is the avowed aim of most economic planners, while it is inconsistent with the basic principles of the free enterprise system. A large part of the material progress of the last hundred years has been due to the cheapness of transportation and the consequent growth in international trade. A large part of the scientific progress of the same hundred years has been due to the greater ease of communication between scholars in distant countries. National self-sufficiency in material resources is too apt to lend to national self-sufficiency in intellectual matters. Nazi *ersatz* rubber, cotton and butter go with Nazi science and Nazi art; the Communist five-year plans go with Communist eccentricities in the teaching of history and economics.

(3) In the production of new goods scientists and those who use their discoveries are constrained to produce goods for which there is an effective demand, *i.e.*, goods that some one will pay for. Under a system of free enterprise those are mainly goods yielding direct satisfaction to individual consumers, and the greatest profits are made by producing

goods for which the demand is most widespread. Because most people, under any system of society, have small incomes it is worth while to produce goods cheaply, so that sales may be as large as possible. The people choose the comforts and luxuries which they desire, undeterred by the mutterings of moralists. And who can be a better judge of a man's wants than the man himself? Under a planned economy some person or group of persons, whether atheistic radicals or fundamentalist conservatives, determines what is good for the people, what shall be produced and how much. Even if such plans worked as contemplated, which they rarely do, they would result in depriving individual citizens of their freedom of choice. Moreover, they would put a full stop to the attempts of scientists and business men to devise new goods to satisfy new wants. Ruling classes do not want their subjects to have new wants. In other words, a planned economy would freeze the standard of living of the individual citizens at or below its present level, although it might make the state more powerful in war.

(4) By the use of new materials or new sources of power, scientists have contributed to lower the cost and improve the quality of goods already known. Here, however, a large part of the credit should go to the business man, since improvements in factory organization and administration and selling methods have been very important in reducing costs even when materials and sources of power have been unchanged. Many of the technological and administrative improvements have been of a sort that would not have been permitted by a totalitarian state, partly because of their effect on other producers who were unwilling to readjust themselves, and partly because many of them seem to cause a lessened demand for labor. Although no one has a moral right to be subsidized by the government if he continues to be inefficient after his competitors have discovered ways to market goods at less cost, or after his customers have discovered cheaper ways to satisfy their wants, it frequently happens that the inefficient groups have political influence, and if the state is accustomed to interfere in industry that influence can be used to obstruct progress. Witness the NRA, the fair-price laws, the anti-chain store legislation, etc. As for unemployment, history has shown that so-called labor-saving devices increase the demand for labor in general although they frequently have an immediate effect in decreasing the demand for certain specialized types of labor and certain individual laborers. These individuals and types often have enough influence on the government to prevent the introduction of devices that would benefit society.

The increased productivity of the human race in the last century is a direct result of the application of scientific knowledge to the affairs of every-day life. More effective use has been made of the world's natural resources. It is true that some new resources have been discovered, but they have not been so much superior to those previously known that they can explain the enormous increase in production. The mere opening up of new areas for settlement or the discovery of mineral resources similar to those already known could permit, and has permitted, an increase in population, but would not by itself increase the per capita productivity of the population.

If any one is tempted to attribute the tremendous increase in productivity and in the purchasing power of the masses in this country to the existence of a vast undeveloped frontier, he should pause and consider:

(1) That Great Britain and Sweden enjoyed similar, and almost as great, advances in standard of living, although neither had an undeveloped frontier;

(2) That Russia and Brazil with equally large undeveloped areas, did not enjoy comparable advances;

(3) That the improvement in per capita income in this country was faster after 1890 than before that year, although after 1890 the frontier had practically ceased to exist;

(4) That during the whole period from 1820 to 1930 there was a trend of migration from the rural districts to the cities, and after 1880 this trend was much more important, absolutely as well as proportionally, than the trend to the rural districts.

No, it is plain that the improving standard of living was the result of improved technology and organization, not of expanding territory or the occupation of more fertile land. And it is also plain that the improvements in technology and organization resulted not only from scientific thinking and experimenting, but also from the risk-taking of individual entrepreneurs seeking for profit.

It is not fashionable nowadays to use the kind of language Adam Smith used when he spoke of the "invisible hand." Smith wrote that the individual "generally, indeed, neither intends to promote the public interest, nor knows how much he is promoting it. By directing his industry in such manner as its produce may be of the greatest value, he intends only his own gain, and he is in this, as in many other cases, led by an invisible hand to promote an end which was no part of his intention." Although the idea of this is essentially sound, perhaps he would have been on still sounder ground if he had merely stated that the individual frankly promoting his own welfare is no more apt to harm others than the individual ostensibly promoting the public welfare, and that it is doubtful who does the most harm to society—the hypocrite who pretends to serve the public in order to benefit himself or the pernicious altruist who pushes his panaceas down the public's throat in a determined effort to do good no matter what it costs. Against the activities of individuals in business other individuals can defend themselves. Against the activities of corrupt or ambitious politicians or of fanatical altruists in possession of the power of the state, individual citizens have no defense. Moreover, individuals in business will have little occasion or opportunity to interfere with scientific research, except occasionally to subsidize it, whereas totalitarian states must in self-defense control scientific thought, or at least its expression.

We do not need to rely on our judgment of human capacities and human motives to support these assertions. They are overwhelmingly supported by the experience of three thousand years. Adam Smith and the other early advocates of the system of natural liberty had little to offer as arguments for their belief except appeals to "natural rights" and, what was more convincing, descriptions of the universal inefficiency of planned economy, because there had been few periods in history when governments and religions had permitted individual business men and consumers to function freely, and their history was obscure. But the planned economy of his day, which was mercantilism, plainly restrained production, and the planned economy of medieval times, which was the guild system in industry and the common-field system in agriculture, had plainly failed to bring about a decent standard of living for the masses.

In ancient times the rights of the state had been regularly exalted above the rights of the individual, business had been despised and industrial labor relegated as far as possible to slaves. Many enterprises were carried on by the state through its own officials, and private enterprises were closely regulated.

The standard of living of the masses was very low. The population of Greece declined rapidly after the time of Alexander and the population of Italy after the time of Julius Caesar. Science was

mainly speculative and contributed little to increase productivity or ameliorate living conditions. After the second century A.D. there were no scientific contributions worth recording, and even technological skill deteriorated, although the Roman state maintained its power and prestige until the end of the fourth century. Perhaps the degenerate Romans were unfit for any form of government but despotism. Perhaps on the other hand despotism made them unfit.

The failure of planned economy in ancient, medieval and early modern times was apparent. The attempt to impose it on the American colonies stirred up so much opposition as to result in the Declaration of Independence, and the establishment of a nation based on individual liberty and free enterprise.

Perhaps some friend of governmental economic planning may assert that its failures in the past have been caused by the stupidity or lack of training of the officials in charge of it. But no scientist seriously maintains that the human race is any less stupid now than in the days of ancient Greece and Rome. Aristotle and Euclid and Ptolemy were doubtless as intelligent as Newton and Einstein. Pericles and Caesar and Marcus Aurelius were doubtless as intelligent as any present day ruler. The bureaucrats of the Roman Empire were carefully trained in universities and law schools, and had a high *esprit de corps*. The bureaucrats who worked for the "enlightened despots" of the eighteenth century were likewise trained in universities, and the science of statistics was invented to help them in their work. But even in those days, when the contrast between the educated rulers and the uneducated masses was greater than now, it proved to be true that most men could manage their own businesses better than others could do it for them.

We are more fortunate than Adam Smith. We have, to help our judgment, not only the horrible examples of planned economy that he had, but new varieties such as Communism, Fascism, Naziism and various aspects of the New Deal. We also have the amazing record of achievement under the comparatively free system prevailing in the United States, Great Britain, and some other European states in the nineteenth and early twentieth centuries. Even with the example of these countries before them, countries like China and Russia with vast areas and variegated resources were unable to equal the achievements of the free nations, because they were not free. Despotism in the one, and ancestor-worship in the other, were able to block progress. If national planning had been a fit instrument for effecting national progress, the highly centralized government of Russia and the highly trained civil service of China should have been able to raise their nations' standards of living at a rate comparable with that attained by the free nations of the West.

History thus shows that when power over the economic affairs of a nation is concentrated, industrial progress slows down and ultimately ceases. At the same time scientific progress in general slows down or is directed into lines approved by the authorities, where the efforts of scholars are either futile or destructive. The officials who proclaim themselves guardians of the interests of the people refuse to permit the people to decide their own interests and their own preferences, and to attempt to satisfy one another's needs and desires.

By contrast, the system of free enterprise is based on the principle that each man shall decide for himself how he wishes to spend his income, and that any one who wishes to offer his wares to the public, for them to choose among, may do so. The consumer votes every time he

spends a cent or a dollar what shall be produced and who shall produce it. The various producers and would-be producers have no power of compulsion over their customers; they must rely on persuasion, not force. They have no authority to suppress rival producers or to suppress criticism of their wares, and most important of all they can not prevent improvements in products and in processes. By the same token they can not prevent scientific progress. In fact they must encourage it, for the best way to get customers away from other producers is to make a better product, or a cheaper one or a more acceptable substitute. Under this system science and human welfare have made enormous strides.

Consequently, any one who desires that the progress of science shall continue must oppose the current tendencies to government regimentation. He must oppose the direct regimentation of science and likewise the regimentation of business, both because the regimentation of business inevitably lends to the regimentation of science, and because the regimentation of business would reduce the demand for scientific discoveries and retard the beneficial utilization of such discoveries as might be made.

We have had a taste of freedom in this country and Western Europe during the last century and a half. The taste has been good and its effects beneficial. We are now offered a draught that on analysis reacts like the water that our ancestors drank from the bitter well of despotism. It has been sweetened and colored to look different, but in concentrated doses it has brought great suffering to our friends in Russia, Germany, and Italy, and the few drops that we have imbibed have already had a debilitating effect on us. To take more now would indicate that we are unable to learn by experience; and I think that the readers of this MONTHLY will agree that he who is unable to learn from experience is not worthy of the name of scientist.

SERIOUS DAYS

THREE days ago a substantial proportion of both the student body and the faculty of Haverford College were registered on this campus for what the Selective Training and Service Act calls "work of national importance." I had thought that the faculty at least were already doing work which deserved to be so characterized, but perhaps not.

The long arm of the state, reaching out to this tranquil, self-governing community, has thus given us a reminder of its pervasive and inexorable power. For the moment it is only a reminder, but even so this registration must be regarded as a portent of the new and difficult age we are entering. All too clearly it foreshadows the unwelcome but inescapable problems which loom ahead for this and educational institutions of similar character. If we are to save our privately endowed colleges we must give close attention to the way the tides are running.

A bitter paradox underlies many aspects of our era. The marvelous achievements of science are being used to destroy the civilization which science has achieved. Learning has been directed to the obliteration of its own temples. The great ideals of human liberty are led to the sacrifice by those who would preserve them. But of all the paradoxes around us none is more disconcerting than the fact that we, living during one of the greatest upheavals of recorded history, have so little understanding of the historical significance of our own times.

For some this lack of insight need not be disturbing. The physician, for instance, is fulfilling his social function if he faithfully follows his mission of healing. The architects who design, and the engineers who execute, can rest with an easy conscience at the close of each day's construction. Even the newspaper man, though frequently devoid of both rest and conscience, may preserve self-respect by adequately presenting and inadequately analyzing the day's events as they develop. But for the educators, at least for those who are not merely vegetators, the times are fraught with a peculiar tribulation.—*Inaugural address of Dr. Felix Morley as president of Haverford College.*

FOOD SUPPLY OF CONTINENTAL EUROPE

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CONTINENTAL Europe is under blockades which hinder importation of foodstuffs. The British blockade is on the surface of the sea; the Axis blockade is under the surface. Europe also faces a pseudo-blockade by Russia. Under these circumstances, the population of Continental Europe must expect to subsist through the winter on the inbound carry-overs from last year and the yields of the 1940 crop. It is important at the outset to define area and population of "Continental Europe" in this article.

Continental Europe is the area west of Greater Russia, north of the Mediterranean, east of the Atlantic Ocean, and south of the Polar Sea, but not including the United Kingdom. In Soviet Russia are now included Finland, Estonia, Latvia, Lithuania and Bessarabia. The United Kingdom stands apart, because it has open sea-ways to the overseas sources of supply, which the blockades exclude from access to the Continent.

There are but two countries north of the Alps still neutral and not under the control of Germany—Sweden and Switzerland. It is to be inferred that Sweden, Portugal, Spain and perhaps Switzerland, will import, under British permits, stipulated amounts of foodstuffs.

Including adjustments for recent boundary changes, the population of Continental Europe, as herein defined, is probably in the neighborhood of 310–320 millions. The question before these countries is whether they can be nourished on the European food supplies, without development of (*a*) obvious but not serious, (*b*) moderately significant or (*c*) severe reactions of famine upon public health, including incidence of disease and death rate. The matter is not made simpler by suggestion that food habits be changed as supplies dwindle—that population is to turn towards vegetarianism, and plant foods not now regarded as edible are to be used as stretching substances. Europe has not forgotten the "winter of turnips," the use of bulrushes in bread, of beech buds in soup, etc. There is no quantitative definition or numerical measurement of famine in the early stage of food shortage, since effects are irregularly cumulative, as illustrated in various countries in Europe during the years 1916–1925. An arithmetic average may be most misleading. Whenever a significant food shortage occurs, individuals are certain to suffer; the question is the number, sex and age, and location in place and in income class.

The food supply is a bundle of edibles. The important groups in the food supply of Continental Europe may be grouped under:

(1) bread grains,
(2) fodder grains,
(3) oil seeds and their products,
(4) sea-food.

I. Small grains grow well over most parts of Europe and laterly selections have improved yields. Oats are raised in the northern areas, where other grains do less well; rye is raised in cold climate and with poorer soils. Wheat is grown in nearly all countries, corn more or less everywhere south of the latitude of the Alps. Since the World War, the growing of wheat has been significantly expanded geographically (by selection and use of appropriate

methods) so that the acreage now regarded as normal is perhaps ten million acres more than before the World War. This increase in acreage (with selection of better varieties and application of fertilizer) has resulted in significant increase of the potential wheat crop. Thus, good or average crops of wheat secured in the thirties exceed the crops of the twenties by several hundred million bushels. The improvement in crop of rye has been less.

The importation of wheat has declined during the last decade, more or less as result of increase in crops of bread grains. Thus, the "Continent of Europe" in a fair crop year in the twenties imported more than 400 million bushels, whereas in a good crop year in the thirties, less than 200 million bushels were imported. This indicates, comparative advantage aside, that economic nationalism produced results in crops. But no one in the Axis powers, or in the surrounding countries subject to them, pretends that enlarged wheat production in the net-importing countries could be further expanded to cover needs, though in an occasional year a bumper crop might nearly do so.

There are four wheat net-surplus countries in the Danubian region—Hungary, Yugoslavia, Roumania and Bulgaria. These have been competitors of Russia and overseas wheat-surplus countries in supplying wheat. But even under favorable conditions they could not be expected to take over the total burden of supply of wheat to the Continent of Europe; certainly under present conditions of disorganization, no such prospect is conceivable. Therefore, with normal bread-grain crops, it follows that in the forseeable future the Continental food supply would be short to the extent of bread-grains previously imported from overseas. And, these may be taken roughly as 160–200 million bushels in recent years.

The crop of 1940, however, was not a large wheat crop like those of '39 and '38, not even a "normal" wheat crop; it was probably the smallest wheat crop in a decade, and one of the smallest wheat crops since 1920. Crop shortage was due to severe winter-killing, heavy floods in the spring, and disturbances by war in Poland, Holland and Belgium. Using the published estimates of the U.S.D.A., with trade estimates in different countries of Europe, it would seem necessary for "Continental Europe" to regard the available supply of new wheat at less than 1,300 million bushels and of rye as less than 800 million bushels, together less than 2,100 million bushels of bread-grain, to be raised or lowered when more accurate estimates are available. The gross figure includes grain for seed and also for feeding to animals. The inbound carry-over of bread-grain is supposed to have been in excess of previous years, due to occurrence of successive good crops and to storage for war.

The implication of the crop, however, is not as high as the figure. Whenever war occurs, peasants tend to hoard grains and hide animals—a normal psychological behavior in peasants. Such withdrawal is made more active if price, trade and transportation are abnormal or unsatisfactory. Seizure of grain by police may be easy when it can be readily moved, but becomes difficult when this is not the case, which applies to the present conditions in the Danubian countries. Also, where peasants have been compelled to accept goods instead of money, antagonism has been aroused. Fluidity of movement of grain has been lowered in the Danubian states during recent years and requisition is difficult, except where a terroristic government is strong enough to override local resistance.

The larger the proportion of imports needed to meet requirements, the more

difficult becomes distribution from outside. It, therefore, seems inevitable that with continuation of blockade, with a short bread-grain crop and with disturbing difficulties in transportation between states and within states, the bread available through ration or through allotment of flour, is sure to be more or less heavily reduced. Europeans are heavy eaters of bread (over 5 bushels of wheat and about half as much rye per capita is the continental need); shortage is at once felt unless the lacking calories can be replaced with potatoes, sugars, fats and vegetables.

Ordinarily speaking, in the case of bread there is not as much concentration of effect of shortage on low-income classes as in the case of shortage in fats, meats or dairy products. The bread grains are calory foods, and have their major importance in maintenance of body weight and manual work. Thus, shortage of bread grains is less injurious than shortage of dairy products and fats of comparable extent. When the supply runs short, the first effect is loss of body weight, which may be slight or extend to emaciation if long continued.

II. Europe has gradually become more and more dependent on imported fodder grains. These include corn, oats, barley and rye; even the imported bread-grains contribute to feeding stuffs to the extent of nearly 30 per cent. To these must be added the oil seeds (meal and cake) which are imported. The primary purpose of import of such grains and oil seeds is to supply protein, the carbohydrate being secured from pasture. The extent to which the imported protein contributes to edible animal products is impossible of computation, but it is heavy in many countries. It is, of course, to be kept in mind that the proportion of meat contributed by imported feeding stuffs is more than is the proportion of imported feeding stuffs related to domestic feeding stuffs, since the maintenance of the breeding herd of younger animals must first be maintained, while imported feeding stuffs are applied mostly in finishing stock for the market.

Certain adaptation is possible, which was practiced by Germany during the World War. Hogs are much more efficient converters of feeding stuffs than cattle; if heavy slaughter of cattle is accompanied by heavy breeding of hogs, a significantly larger supply of meat is secured from a stated supply of feeds. This, however, runs against the views of peasants, requiring arbitrary control and extensive policing of farm products. Any lowering of import of concentrated fodders or shifting from cattle to hogs also disturbs export trade in animal products—very important in Western Europe—and this provokes resistance. The blockades on concentrated feeding stuffs into Western Europe hit Britain hardest, since that country was the heaviest importer of meats and fats from across the Channel and North Sea.

III. The fat and oil supply is the Achilles heel of the European food supply. Soil and climate of Europe are less favorable to cultivate of oil seeds than of grains; therefore, Europe has developed dependence upon direct and indirect importations of oils and fats. Direct importations include coconut, palm, palm kernel, cottonseed, peanut, flax, soybean (and others) as seeds and also as expressed fats. Included further are large amounts of animal fats—lard, tallow, whale oil and other marine fats, and even butter. Indirect importation of fat is secured through farm animals fed on imported feeding stuffs, animals which could not be sustained on domestic feeding stuffs. A number of countries in Western Europe are veritable feeding yards, in which local grasses and imported grains and oil seed concentrates maintain animals upon the artificial scale promoted. As a con-

crete illustration, as soon as Germany took possession of Denmark, Holland and Belgium, their feeding yards had to be curtailed; following reduction of number of animals to the level of feed supply unaided by imports, the outturn of meat and fat will be heavily reduced. The sum of indirect and direct contributions of imports is large in Western Europe.

Fat, however, has other uses than as food, namely, in soaps and explosives, bringing about the "choice between guns and butter," as Goering is supposed to have expressed it. It is possible separately to synthesize glycerine needed for explosives and fatty acids needed for soaps; but developments have not extended to the scope necessary to replace the lacking importations. The extent to which food fats are diverted to propellants in belligerent countries is not known, but the defection is surely significant.

Heavy reduction of import of concentrated feeding stuffs, leading to shortening of the milk supply, is certain to create problems in child health—since milk supplies minerals, balanced protein and vitamin A, which can hardly be replaced when there is shortage in other directions in the food supply. Western European countries have used feed imports both to produce butter from cows and margarin from factories; heavy reduction in such imports will have the double effect of cutting down the milk supply, with its nutritional virtues, and the fat supply, with its industrial utilities.

The effect of shortage of fat upon food supply is not merely one of calories, it is also one of taste. The Germans used to think that sauerkraut was a cabbage dish, but during the World War they discovered that it was eaten more for the fat added to it than for the cabbage. In Europe more than in the United States, fat is the important component in the art of cooking; much of the traditional characteristics of mixed dishes of pastes, meats and vegetables were derived from fats. The lack of fat is a heavy loss in calories, used for the support of body heat and work; unless made good by carbohydrates, the result is sure to be felt in loss of body weight and in working strength. Europe is supposed to have this year a better-than-average crop of potatoes and a good crop of sugar beets, which to some extent are counted on to take the place of fats. Also, there will be an excessive killing of farm animals prior to the first of January (imposed by lack of imported feeding stuffs), which for the time being will serve to replace the shortage of imported fats. The real fat shortage, therefore, is not to be anticipated until after the beginning of the new year.

IV. Fishing has been a prominent food industry in Europe. From the northern tip of Norway to the Gibraltar, fishing fleets operated as far west as Iceland, Newfoundland and down even into the Antilles. Important also has been fishing in the Mediterranean and in the Black and Caspian Seas. Since the World War there has been an extraordinary expansion in whaling, and the contributions of Antarctic whaling to the European fat supply have been surprisingly heavy.

The stress laid upon sea food earlier in the diet in Europe was based largely upon the use of fish as substitute for meat. At present, however, the importance is recognized to be more significant in a different direction, namely in the contributions of iodine and vitamins A and D. These two fat-soluble vitamins are located more or less throughout the bodies of fish, but particularly are concentrated in the liver, and are rather scarce in most foodstuffs. The inability of fishing fleets to operate in the company of mines, submarines and airplanes inflicts upon the population of Europe a

slightly significant loss of protein and calories, but a highly significant loss of fat-soluble vitamins. Lacking vitamin A and D from sea food, the otherwise European diet could hardly provide vitamins A and D to cover minimal needs, and widespread deficiencies will arise, particularly in the poorer classes. When in the World War, the interior inhabitants—for example, in Austria—were deprived of sea foods and cod liver oil, rickets became common and severe. Under comparable circumstances, deficiencies in vitamins A and D will occur again, largely in the poorer classes, in severity dependent upon other factors. It is perhaps a significant commentary on the situation to say that at present fish liver oils are being shipped from the Pacific Coast to Great Britain, in order to replace the extinguished supply from the North Sea and North Atlantic.

It is, of course, true that vitamin A from fish supply is only one supplementary source of vitamin A; but it is a very important one, particularly in certain regions. Vitamin A enters the diet in milk and in many fruits and vegetables. The history of Northern Europe makes it clear that if vitamin A from fish and milk are both scarce, then vitamin A from plants can not be relied upon to cover needs.

The present art of the chemist does not insure commercial synthesis of vitamins A and D. In the presence of adequate sunshine, vitamin D is dispensable in the diet; but Europe north of the Alps does not have sufficient ultraviolet light to prevent rickets. Therefore—on the basis of experience in northern Europe over the last hundred years, and particularly the experience during the World War and since—an increased occurrence of deficiency diseases due to shortage of vitamins A and D is to be expected, more or less widespread in different countries north of the latitude of the Alps and occurring especially in the lower-income classes.

V. The food shortage connected with the World War was in three periods, differing in cause, incidence and effect—namely, food shortage during hostilities, during the Armistice and during reconstruction after reestablishment of peace, which lasted in most countries until 1924. European countries are now in better statistical position to appraise their situations than then; also, the newer knowledge of nutrition will aid in guiding remedial measures.

Each country will attempt to stretch the food supply by rationing. The hungry can not subsist on averages; it is possible for a fifth of a population to suffer health-devastating shortage, while the four fifths manage to get along. A ration, more or less in different countries, has four purposes. The first is to prevent the rural districts from using more than the share belonging to them. The second is to provide equity between income classes. The third is to make special allocation of protective foods, especially to children. The fourth is to provide added calories for hard-working adults. A ration may be carried out with free prices, with controlled maximum prices or with fixed prices under state subsidies. The latter plan alone seems capable of providing effectively for the second and third purposes of rationing. The older technique of rationing was thoroughly learned during the World War and is easily revived in all countries. Germany had indirect rationing of certain foodstuffs, such as fats, for a number of years before the present war. But state subsidies, where necessary, may not be easily obtained under present conditions of taxes and currencies. Since all countries in Europe (even the Danubian states) will need to ration, this will make rationing everywhere more diffi-

cult. Particular problems will arise in those countries where agriculture and food supply have been more or less based on imports. Geographically, the more acute problems will arise in the western fringe, beginning with Norway and extending through Denmark, Holland, Belgium and France (with the problem in unoccupied France perhaps even more difficult than in occupied France), since these heavily deficient countries are not in position to barter with the Danubian states. In most countries, a special problem is the feeding of refugees. In the meantime every country in Europe will make strenuous efforts to expand acreage and raise yields in the crop of 1941.

It is important to understand that the food blockades of the two belligerents differ in derivation and in application, but not in fact or effect. In the older literature on blockades is to be found segregation of contraband and non-contraband, then division of contraband into conditional and absolute contraband. In modern war, all articles are contraband, more or less, in use or substitution. There is no separation of civilian from belligerent, only a gradual transition, overlapping of home-front and fighting-front. Britain blockades the Continent of Europe to close all channels to the Axis Powers. The Axis blockade prevents ships from entering Western Europe or Mediterranean countries by sinking without warning. The British take blockade-runners into prize-court, the Germans take them to the bottom of the sea. The practical effect of these blockades is to prevent the countries of Continental Europe from importing foodstuffs from overseas. There is no practical purpose in trying to invoke traditional "legality" or inherent "morality" in interpretation of food blockades. In the modern war—mechanized warfare—all units of population have become participants. Goods and services are one and indivisible.

The word "famine" derives from folklore, not from science, and is arbitrarily used. When the monsoon fails, then follows "famine"; when a city is besieged, the lack of food is called "famine." But when lack of food causes beriberi in the Orient, pellagra in the Balkans, scurvy in Mesopotamia, or zerophthalmia in Denmark, this is not called "famine." Thus, in folklore occurrences of "famine" and "starvation" depend upon forms of deprivation. Dynamically defined, we ought to regard as famine any shortage of food which significantly fails (a) to sustain normal activities, (b) to maintain normal growth and weight, (c) to sustain normal resistance to infectious diseases, and (d) to prevent occurrence of deficiency diseases. Thus famine ought to include a deprivation of particular foodstuffs, as well as general scarcity of food,—and may be mild, moderate, severe or fatal. In this sense should famine and starvation in Europe be judged. In this sense famine has always existed in Europe, in spots and involving small numbers. In war, it is to be expected that famine will expand to cover wider areas and involve larger numbers.

BOOKS ON SCIENCE FOR LAYMEN

HAS THE UNIVERSE A SOUL?[1]

In this interesting book the author attacks an extremely exciting and important problem concerning the applicability of the principles and methods of modern physical theory to the phenomena from the field of biology.

The book begins with a very clear presentation of the fundamental ideas of the relativity and quantum theories, with particular emphasis on the existing *dualism* between the *particles* as the essence of matter, and the *fields* as the "immaterial" (*i.e.*, deprived of mass) leading agents directing the motion of these particles.

The following chapters describe the fundamental biological facts pertaining to the structure, fertilization and division of living cells, and the development of organisms. The rest of the book (about one half) is devoted to the author's own theory in which he tries to describe biological phenomena in a way analogous to the quantum-mechanical description of the atomic phenomena in modern physics. From here on, the reader trained in theoretical physics could not help but wonder. Already in the purely physical part of the book, the author makes an assertion which, though very helpful in building biological analogies, essentially deviates from the ideas accepted in physics. He speaks about the wave-function describing the motion of particles in an atom, as about something existing in the three-dimensional space and possessing certain "objective reality" in spite of the absence of mass ("immateriality"). It is well known, however, that wave-functions describing the motion of mechanical systems could be represented geometrically only in imaginary multi-dimensional spaces, and thus possess no physical reality in ordinary space. Being evidently aware of this objection, the author tries to remove it by saying (footnote on p. 50) that "this is due to the fact that in our observations we can not distinguish one electron from another." This remark is, however, evidently based on some mistake because also in the case of quite different particles (as proton and electron in the hydrogen atom) the wave-function can not be represented, strictly speaking, as a function of only three coordinates. The only case when the three-dimensional presentation of the wave-function of a system is possible is the case when the separate particles do not interact at all with one another. In this case the multi-dimensional wave-function splits into three-dimensional components in the same way as the three-dimensional motion of a particle in classical mechanics can be split into three one-dimensional motions if the potential energy is the product of three independent functions (separation of variables).

This erroneous assertion brings the author, in the way of analogy, to the introduction of "immaterial living wave functions," or "genii," existing in three-dimensional space and leading the motion of different parts of living cells "in the same way as wave-functions of quantum theory lead the motion of electrons in an atom." Besides the above-mentioned fact that the analogy here is missing, it is quite unclear why the author uses the prefix "wave." In quantum theory the introduction of wave-functions became necessary after it was found that the electron-beams show the characteristic phenomenon of diffraction which could not be described in the language of particles. Since in the field of biology no phenomenon analogous to diffraction of light or electron-beams has been as yet discovered, the

[1] *The Soul of the Universe.* By Gustaf Strömberg. xviii + 244 pp. $2.00. 1940. McKay.

prefix "wave" is quite misleading and serves only to stress the non-existing analogy with the phenomena of quantum-physics.

It is still less clear why such dualism should be introduced at all in the description of biological phenomena. The dualism in physics was the result of the discovery that the motion of particles possesses certain wave-characteristics which could not be united with the particle characteristics in one simple mathematical scheme. The wave- and particle-aspects in physics reveal different sides of the motion, and are in this sense *complementary*. The "living wave-functions" introduced by the author do not possess this property of complementarity, and simply repeat everything that the material cell does. The "genii" grow, divide, etc., when the cell goes through the same stages, and this doubling of the process does not explain anything. The tautology resulting from the introduction of the word "genie" is broken only by the author's assertion that "the genii can exist and retain their properties, even when they are not associated with matter," which he finds necessary to explain the eternity and transmigration of souls. But here the analogy with the quantum-mechanical wave-function entirely breaks down!

Concluding, one must say that whether these "genii" really exist or not, *they certainly do not represent the slightest analogy with any notion used in modern physics*. Apart from the badly fitting disguise-dress of physical terminology, these "living wave-functions" are practically identical with the centuries-old ideas of soul, spirit or the mysterious "élan vital" of the old biology.

G. Gamow

LO, THE POOR INDIAN![1]

The curator of anthropology of the American Museum appeals in this work to a wider, and less serious, audience than in his "American Indian." There are two ways of giving readers of this class a "taste" of the subject. Either matter may be abstracted and highly condensed in an attempt to cover the whole field, or the field may be sampled in a few select studies appealing more largely to the imagination and the emotions, and sometimes in fictional form. Dr. Wissler has chosen the first method and has brought the high-lights of his subject before the reader exceedingly well, but his style suffers from the intense compression to which the material has been subjected, especially in Part II. Part I is a brief review of "The Indian in Prehistoric America," Part II a consideration of "The Great Indian Families" and Part III a discussion of "Indian Life in General." There is a page of suggestions for further reading and an appendix of six pages answering questions regarding the Indian which Mr. Average Man is most likely to ask.

Whoever attempts a general work of this character inevitably exposes himself to scalping parties of specialists, and they will not have much difficulty in finding opportunities to count coup in the present instance. Dr. Wissler's classifications are evidently intended to take in as large areas as possible and that may explain the unexpected allocation of some of the tribes. If Salishan tribes are to be classed as "possible members" of the Algonkin family the Wakashans should also. The Tobacco Nation should have been added to the list of independent Iroquoian tribes, and the Missouri—having given their name to a state—should have been added to the Siouans. One's breath is somewhat taken away by the extension of the Penutian family, and, if we remember rightly, Sapir placed the Tsimshian in this group rather than with the Na-Déné. The author is at least up to date in listing the Mayans under the Uto-Aztecans. The arrangement of the Caddoan tribes, however,

[1] *Indians of the United States.* By C. Wissler. Illustrated. xvi + 319 pp. $3.75. 1939. Doubleday, Doran and Company.

certainly needs revision. Caddo is the most aberrant dialect and should stand by itself. Wichita and Kichai should be coordinated with Pawnee and Arikara, and Tawakoni and Waco be placed under Wichita.

Unfortunately, there are blunders of a more regretable character. For instance, Kentucky does not mean "the dark and bloody ground" (74), the Sheyenne River of North Dakota has been confounded with the Cheyenne River of South Dakota (92), Ojibway and Chippewa are two forms of the same word and belong to one people (97–8), the "original Algonkin" were in the western part of the Province of Quebec and distinct from the Ojibway, Menomini and Potawatomi (99), the Huron were not identical with the Tobacco Nation nor the Neutral Nation with the Erie (113–4), the Tunica Indians were allies of the French and not annihilated by them (147); in speaking twice of "the boundary between Mississippi and Georgia," Dr. Wissler has crowded Alabama off the map (148–9), the Caddo did not "hold the river front" on the lower Mississippi in historic times, not in fact extending east of the Ouachita (155); Minnesota signifies "clear water," or water having a slightly milky appearance, not "waters many" (158), Canada became British territory in 1763, or 1760 if the conquest date is desired, not in 1754 (164), the survivors of the eastern Siouans are found in South Carolina, not on the lower Mississippi (178), and by "late in 1600," "early in 1700," and "early in 1800" we are evidently to understand the seventeenth, eighteenth and nineteenth centuries, respectively.

Part III is by far the best section, but, as a center of population density, Florida should not be excluded from company with the other southern states (239), maize certainly could have sustained many eastern tribes for "a part of the year" if not sometimes for an entire year (241), part of the agricultural work in the Southeast was done by men, not all by women (242), it would be nearer to the truth to say that white men rarely understood Indians than to say that they "never" did (270), the black drink was not a narcotic (296), and many will hesitate to categorize "head shrinking" among the "important inventions" (295).

The answers to queries are generally excellent, but a few emendations are called for. Shell money was, of course, used on the Pacific coast, but there it should not be called wampum (303–4). In fact, wampum was originally confined to the neighborhood of Long Island Sound. In the Southeast men and women danced in some dances together though not after our fashion (304). The Great Chief of the Natchez possessed something like arbitrary power and so did many of the heads of leading families on the north Pacific coast (305). Mulberry bark was more important than nettle fiber as raw material for textiles in the Southeast (306).

We are conscious of too many glass windows of our own to enjoy throwing stones, but it really seems as if a little more editorial care might have eliminated most of these slips, and there is no reason why a second edition should not make this a noteworthy publication.

John R. Swanton

TWINS AND SUPERTWINS[1]

The criticism has frequently been made that scientists have been remiss in making known their discoveries to the public at large. The book "Multiple Human Births" is a direct refutation of this accusation, for not only does the

[1] *Multiple Human Births.* By H. H. Newman. Illustrated. xv + 214 pp. $2.50. 1940. Doubleday, Doran and Company, Inc.

author give a clear and readable account of the work done in trying to solve the various questions which arise in connection with the study of twins but even further this is the first of a series of popular accounts of scientific work to be published by the American Association for the Advancement of Science. The choice of the topic is a happy one, for every one is interested in twins and many advances in our knowledge have come as a direct result of investigations on them. Here nature has set up for us an experiment and in the one-egg twins has provided two individuals with the same heredity. In such cases the effects of varying environments can be studied. Many workers in many parts of the world have investigated different angles of the problems involved. For the first time their work has been summarized and put into such a form that any one can know what has been done. Dr. Newman has been very fortunate in presenting his subject so that it will be readable and easily understood without making it too simple.

When one thinks of twins many questions come to mind. How are twins formed? What about triplets, quadruplets and quintuplets? How many kinds of twins are there? Do twins run in families? How much alike are twins? Why? What can be learned from twins about human heredity in general? What has been learned from the study of the Dionne quintuplets? All these and many other questions are raised, discussed and answered in this book. The embryologist, the geneticist, the psychologist and the sociologist will find the material presented useful and worth while. The lay reader will here find a real adventure in store. For those who wish to continue the study a good bibliography is included. To quote, these "researches have shown conclusively that the human heredity-environment problem is extremely complex, that it is not one problem but many, that the problem differs with respect to every character studied and there is therefore no general solution for the problem as a whole. . . . There remains much to be done."

D. B. YOUNG

MEN AND GLANDS[1]

A SUBTITLE qualifies the book as "An Introduction to Constitutional Psychology." It could have more fittingly, perhaps, been called "a highly involved treatise on the effects on the human body and mind of glandular and other pathology."

The volume impresses one strongly as a large but vain effort to sustain and advance a line of theories of not even indigenous origin; theories which, except in a few points, find no confirmation in biology, or normal authropology, anatomy and physiology. The authors fail to see that they are dealing with all sorts and grades of aberrations from the normal; that their classifications at one time of the life often change in the same individuals as they grow older; that these classifications fail with people of other races; and that even in Whites, at a given time, there are innumerable transitional cases and uncertainties that will baffle even the best judgment. Unfortunately, fallacies are stronger than reason, and serious critical work and travels are hard and untasteful.

There is an over-extensive index, many parts of which are quite useless, while others (p. 328) are displaced. It is strange that the publishers, with their great experience, have passed such an index.

ALEŠ HRDLIČKA

[1] *The Varieties of Human Physique.* By W. H. Sheldon. Illustrated. vii + 347 pp. $4.50. 1940. Harper and Brothers.

THE PROGRESS OF SCIENCE

GEOFFREY CHAUCER, 1340?–1400

Born six hundred years ago and still alive! How few are the poets of which this can be said! Fewer yet are those who, having come so early, have worn so well. Chaucer is not a classic read merely out of respect to a reputation in the past; he is read as a present source of delight and joy. The oldest of the major English poets, the first of the royal line, he is in some ways the most modern. And his germinating power is still vital. The Poet Laureate to-day is a disciple of Chaucer and has said that when first he turned to the making of poetry, it was in Chaucer that he found the kind of thing he most wanted to do.

Chaucer's life was a varied and busy one, quite apart from literature. As soldier, courtier and man of affairs, he spent most of it, from youth up, in fairly close touch with the court circle. Page to the Countess Elizabeth, squire in the king's household, controller of customs, emissary and diplomatist of two kings on seven or eight missions abroad, sometime Justice of the Peace, Member of Parliament, Clerk of the Works, Sub-forester of the King's Forest, etc., etc., Chaucer is the triumphant refutation, once for all, of the popular notion that poets are a long-haired, dreamy-eyed fraternity incapable of attending to practical affairs and a little insane.

Among other things, Chaucer was a man of learning, widely read in several fields besides literature. He was not what we should call a scientist, but his knowledge of science, or of what passed for science in his day, was great. His "Treatise on the Astrolabe" is a scientific work. His poetical writings are studded with references to astronomy and astrology. In various passages he shows detailed knowledge of the theory and practise of medicine in his day, and in the "Canon's Yeoman's Tale" intimate acquaintance with the terms and practises of alchemy. In the "House of Fame" he gives an account of the theory of the transmission of sound which will pass muster to-day. And in dealing with dreams and the problem of foreknowledge and free will, he shows that he is versed in philosophy, metaphysics, theology and what is now psychology. Something of the scientist is seen, too, in Chaucer's love of facts. No poet since Homer has had a keener eye for facts, for solid, concrete facts; nor is there any whose work is more firmly based on fact. The Prologue of the "Canterbury Tales," for example, owes its success to Chaucer's brilliant command of facts and power of using them artistically.

To speak of Chaucer as poet is to seem to exaggerate; one must use so many superlatives and claim so many "firsts." The founder of the great tradition in English poetry, all subsequent English literature is enormously indebted to him. He is the greatest of narrative poets, and among his works are discovered the first examples of the modern novel and the short-story. He is the first realist in English literature, the first humorist, the first master of character portrayal, the first great exponent of life-like dialogue. In these respects he is not only the first but one of the best.

No better specimens of the fabliau are to be found anywhere than the tales of the Miller, the Reeve, the Merchant and the Summoner. The "Nun's Priest's Tale," besides being a perfect fable, is a mock-heroic poem unexcelled even by Pope's "Rape of the Lock." The "Man of Law's Tale" and the "Clerk's Tale" are among the noblest examples of pathos

GEOFFREY CHAUCER

FROM A LIMNING IN OCCLEVE'S POEMS IN THE BRITISH MUSEUM. ENGRAVED BY J. THOMSON.

in our literature. And "Troilus and Criseyde" is not only the first novel of character and one of the world's great love stories, but one of the triumphant examples of sustained narrative in all literature, as great in design, in handling of plot, character and background, as in the beauty and finish of its poetry. Finally, Chaucer is the first great English prosodist, whose verse has never been surpassed in ease, simplicity and unfailing melody.

It is a common error to think of Chaucer as the poet only of the "Canterbury Tales," as above all a realist and satirist, who tells bawdy stories, delights in calling a spade a spade, and makes mention of such things as the "stinking" breath of the Cook and the hearty sweating of the Canon's Yeoman. This is the vulgar notion, and the vulgar connotation of the word *Chaucerian.* Of course, there *are* these things in Chaucer, but only because he knows men and women so thoroughly and in such variety, and as an artist with nothing less than a balanced realism which paints characters in the round. So far from being only or chiefly a realist and satirist, he is fundamentally and chiefly a poet of love. As a poet of love he is a poet of nature—of the May morning and the daisied fields—and a poet of beauty, grace and sentiment; of all, in a word, that came from and with the poetry of courtly love in France and Italy—and considerably more. In thinking of Chaucer's women, for instance, we are apt to stress those daughters of the flesh, the Wife of Bath and the trollops of the "churls' tales," and to forget the noble and gracious Blanche the Duchess, the gentle ladies in the "Legend of Good Women," the long-suffering Constance and Griselda, so glorious in their love of their husbands and children, and the fascinating Criseyde. These are much more the typical Chaucerian heroines. And they are all women of charm, tender-hearted and gracious.

Chaucer is not a satirist because he is not a reformer. His method is often satirical, but that is only a way of having fun; it is part of his laughter, his zest for life. And here we come upon what is perhaps Chaucer's most distinguishing characteristic, his glad acceptance of life. In no English poet save Shakespeare is there so much fulness of life. That is why this medieval poet, born six hundred years ago, is still an inspiration and a joy, and why, in spite of his remoteness in time, he seems so near to us in spirit.

PERCY V. D. SHELLY[1]

THE AMERICAN ASSOCIATION RETURNS TO ITS BIRTHPLACE

FROM December 27 to January 2 the American Association for the Advancement of Science will hold its annual meeting in Philadelphia, the place of its birth on September 20, 1848, a little more than ninety-two years ago. In 1848 there were 461 members of the association; now there are about 21,000, of whom nearly 500 are residents of Philadelphia. From its beginning the association has had members from all parts of the United States; now it has members residing in seventy foreign countries.

Philadelphia has been the birthplace of other scientific and cultural organizations and institutions. First on the list is the University of Pennsylvania, which grew out of the "Charity School" established in 1740 and which this year is celebrating its two-hundredth anniversary. It is now one of the great universities of our land, with more than 1,500 officers of instruction and nearly 16,000 students.

[1] Author of "The Living Chaucer." Philadelphia: University of Pennsylvania Press. 1940.

ORIGINAL BUILDINGS OF THE UNIVERSITY OF PENNSYLVANIA

AT FOURTH AND ARCH STREETS, PHILADELPHIA, AS THEY APPEARED ABOUT 1770. THE UNIVERSITY, WHICH WAS FOUNDED BY BENJAMIN FRANKLIN, WAS THEN KNOWN AS THE ACADEMY. THE BUILDING AT THE LEFT (WITH STEEPLE) WAS BUILT IN 1740 AS THE HOME OF THE CHARITY SCHOOL, TO WHICH THE ACADEMY SUCCEEDED. AT THE RIGHT IS THE DORMITORY BUILDING ADDED IN 1762. (FROM A PAINTING BY CHARLES M. LEFFERTS IN 1913.)

The second of the great institutions born in Philadelphia is The American Philosophical Society, which was organized by Benjamin Franklin in 1743 as an informal group of "lovers of wisdom"; in 1780 it secured a charter and became a formal and permanent organization. The Academy of Natural Sciences of Philadelphia was founded in 1812; The Franklin Institute in 1824; the Delaware County Institute of Science in 1833; and the Wagner Free Institute of Science in 1847. There are also several educational institutions of distinction in Philadelphia and suburbs, such as Haverford College, Swarthmore College, Temple University and Drexel Hill Institute of Technology.

Philadelphia is also noted for its amateur scientific organizations and the cultural means it provides for adults. A recent survey under the supervision of The American Philosophical Society reveals the fact that in the city there are now 287 active amateur scientific organizations with a total membership of more than 32,000 persons. The special interests of these societies lie in many fields of science—astronomy, botany, earth sciences, microscopy, ornithology, conservation, photography, etc. There are available for the use of the members of these societies and other interested persons 72 "institutes, libraries, observatories and similar science facilities." There are, indeed, six astronomical observatories in Philadelphia and its suburbs, as well as the Fels Planetarium of The Franklin Institute. If an adult resident of Philadelphia desires to enter upon formal study, he will find that he may choose from 120 courses in 19 different fields of science. In addition to the facilities for the advancement of science provided by the universities, colleges, institutes, museums and libraries of Philadelphia,

THE SCHOOL OF MEDICINE OF THE UNIVERSITY OF PENNSYLVANIA

FOUNDED IN 1765, IT WAS THE FIRST UNIVERSITY SCHOOL OF MEDICINE IN AMERICA. THERE WAS ALSO ESTABLISHED AT THIS UNIVERSITY IN 1769 AMERICA'S FIRST FORMAL PROFESSORSHIP OF CHEMISTRY. BENJAMIN RUSH, ONE OF THE FOUR FOUNDERS OF THE SCHOOL OF MEDICINE, WAS THE FIRST INCUMBENT OF THE CHAIR.

there are 94 research laboratories maintained by its great industries.

Philadelphia is indeed a distinguished city with a long and glorious past. The statue of William Penn, its founder, looks down upon its central business district from above the City Hall. It was in Independence Hall that the Declaration of Independence was signed in 1776, and there rests the famous Liberty Bell. This city was the capital of the United States under the Articles of Confederation from 1781 to 1789, and under the Constitution from 1790 to 1800. In

it was established the first public school in America, the first public library, the first bank, the first insurance company, the first law school, the first university medical college for men and for women, the first college of pharmacy and the first municipal water system. Here Benjamin Franklin drew electricity from the clouds with his kite, and here Betsy Ross made our first national flag. The old churches whisper of Sir Christopher Wren. On every hand are reminders of peace-loving William Penn and colonial days, of Benjamin Franklin, the universal genius and of the stirring events attending the birth and early days of the Republic. Here is tradition without snobbery, quality without ostentation. Even where time is taking its inevitable toll there is an enveloping air of lavender gentility.

In many respects Pennsylvania is the most ideally typical American state. Its climate is neither extremely cold nor enervatingly warm. Its commerce has direct access to the sea and to the great rivers of the Mississippi valley. It has fertile soils, and 15,000 square miles of its area are underlain by coal. The Swedes established, in 1643, the first permanent white settlement within its borders. They were followed by the gentle Quakers, who were predominant in Revolutionary Days. There came, also, Dutch and Germans and, in later days, all the other hardy European stocks that have worked in our mines and manufacturing industries. It faced the realities of war in the struggle of the American colonies for independence, for the battles of the Brandywine, Paoli and Germantown were fought on its soil, and Philadelphia was occupied by British soldiers from September 26, 1777, to June 18, 1778. Washington's ragged troops suffered at Valley Forge through the winter of 1777–78, and what is regarded as the decisive battle of the Civil War was fought at Gettysburg on July 1–July 3, 1863.

Many factors have transformed Pennsylvania from a wilderness to what it is to-day. Among them are its location, its abundant natural resources, the fine qualities of the peoples who settled it. But these factors alone could not have made Pennsylvania one of the greatest manufacturing regions in the world. It has been science and its applications that have produced this amazing transformation, which is quite unparalleled in the history of mankind until our day. Science has added immeasurably to our comforts, and it has largely protected us from the ravages of infectious diseases, and, alas, it is also being used for destructive purposes. But the programs of the meeting of the American Association in Philadelphia will be devoted to the constructive applications of science. For example, the chemists will have a program on applications of chemistry to agriculture and physiology; the medical section will present a three-day program of 39 papers on malaria; and the American Philosophical Association will present a symposium on the nature of man. Altogether more than 2,000 addresses and papers will be included in the general program of the association for its Philadelphia meeting.

Although most of the programs of the association at Philadelphia will be for specialists, a number of them will be non-technical and open to the general public. First of these is the address of the retiring president of the association, Dr. Walter B. Cannon, of Harvard University. Another is by Dr. Edmund Ezra Day, distinguished president of Cornell University, who will deliver an address on the timely subject, "Discipline of Free Men." The annual Sigma Xi lecture will be by Dr. A. J. Carlson, of the University of Chicago, on "Science versus Life." Walter Lippmann, noted editor, author and columnist, will deliver the annual Phi Beta Kappa address on a subject that remains to be announced. In addition, there will be

scores of special programs ranging over the fields of the physical, biological, psychological, anthropological, engineering, medical, historical and pedagogical sciences that will be attractive to amateurs. Finally, there will be a science exhibit showing many of the latest investigations, the apparatus and equipment now available for scientific research, and the most recent scientific books.

But professional and amateur scientists will not be the only persons who will learn of the discoveries and progress of science announced at the meeting of the association, for skilled science writers will interpret them in hundreds of clearly and accurately written articles that will be published in the daily press. And why shouldn't the general public be interested in science? Nothing else has so profoundly affected the lives of human beings or will probably so greatly influence them in the future. In order that science shall be used wisely for the advancement of civilization it is necessary that men and women generally shall comprehend its supreme importance, not primarily because of its astounding technological applications, but more especially because of the inspiring picture it paints of the nature of the cosmos and of man.

F. R. Moulton

ENTRANCE OF FRANKLIN INSTITUTE

STATUE OF BENJAMIN FRANKLIN

OF HEROIC PROPORTIONS IN THE FRANKLIN INSTITUTE.

THE COLLAPSE OF THE TACOMA NARROWS BRIDGE

As the Tacoma Narrows suspension bridge neared completion last spring it became apparent that it possessed some characteristics hitherto not encountered in suspension bridges. These differences took the form of marked vertical undulations which occurred under the action of wind. Continual observation indicated that this motion might occur in wind velocities as low as 4 miles per hour if the direction was favorable, and prior to the collapse of the bridge on

November 7 such motion had been noted in wind velocities up to 49 miles per hour.

These vertical undulations developed in several patterns corresponding to various natural frequencies of the structure. The lowest frequency observed was 8 cycles per minute when the main span had on it a single wave. The most violent motion noted prior to the final catastrophic one was at a frequency of 36 cycles per minute, involving ten waves on the main span.

Careful observation had indicated that this motion, which was by no means continuous, was causing no immediate damage; but it was considered advisable to modify the bridge in view of the possibility of very much stronger winds in this locality.

Early in the investigation of this structure it was suspected that the aerodynamic characteristics of the suspended portion of the structure might reveal the source of the trouble. Thus a 1/20 scale wind tunnel model representing 160 feet of the roadway section was constructed with faithful attention to detail. Subsequent tests in the 12-foot wind tunnel at the University of Washington disclosed a condition of serious aerodynamic instability sufficient to account for all the motions so far observed on the bridge. The crowding of the wind tunnel with National Defense problems from the Pacific Coast slowed up

Courtesy of Bashford and Thompson, Tacoma.

TACOMA NARROWS BRIDGE IN VIOLENT WAVE MOTION

THE TWO CABLES FROM WHICH THE BRIDGE IS SUSPENDED EXPERIENCED VERTICAL OSCILLATIONS OF AS MUCH AS 28 FEET WITH CYCLES A LITTLE OVER 4 SECONDS. THE DESTRUCTIVE FORCES WERE INCREASED BY THE FACT THAT THE WAVES IN THE TWO CABLES WERE OUT OF PHASE, THE TOP OF THE WAVE IN ONE CABLE OCCURRING WHEN THE OTHER ONE WAS AT NORMAL POSITION.

Courtesy of Bashford and Thompson, Tacoma.

TWO HUNDRED FEET OF THE TACOMA BRIDGE PLUNGING INTO THE SOUND

FOLLOWING WHICH THE AGITATION BECAME SO VIOLENT THAT THE REMAINDER OF THE 2,800 FEET SPAN FOLLOWED IT WITHIN A FEW MINUTES. WITH THE REMOVAL OF THE LOAD FROM THE CABLES OVER THE CENTRAL SPAN THE TENSION SHOREWARD BECAME SO GREAT THAT THE TOWERS WERE BENT BEYOND THEIR ELASTIC LIMITS AND THE SPANS FROM THE TOWERS TO THE SHORES SAGGED 25 TO 30 FEET, BUT DID NOT FALL.

further testing of devices calculated to improve the aerodynamic characteristics of the structure. Finally, on November 2, a number of tests were completed from which arose a whole series of proposals for the stabilization of the bridge.

However, five days after completion of these tests and before contracts could be let covering the installation of the chosen corrective device the bridge collapsed in a 42-mile wind.

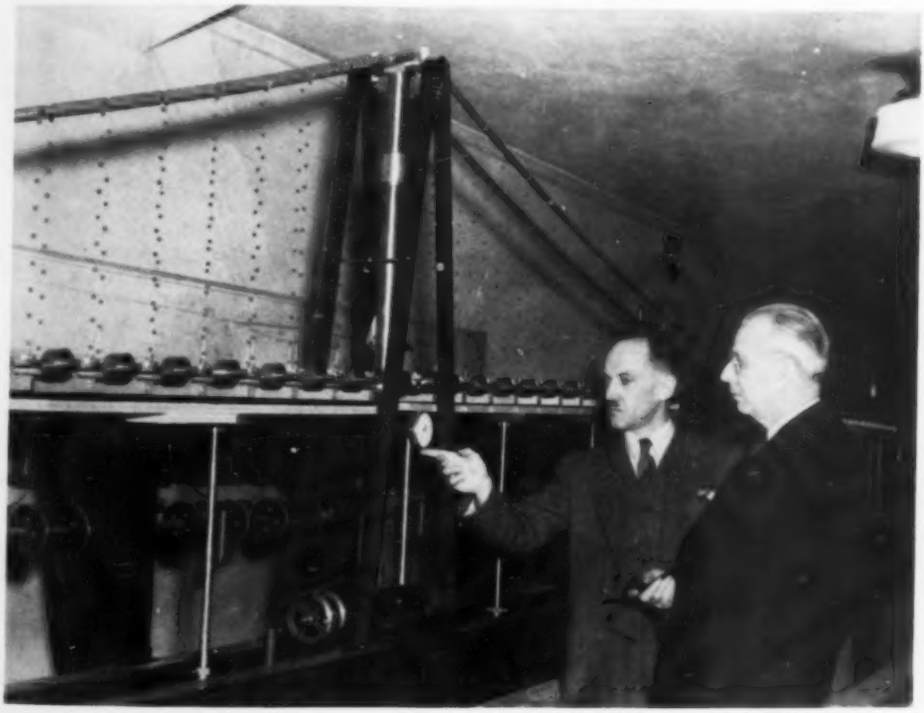
Shortly before 10:00 A.M. on the morning of November 7 the bridge was observed to be moving in characteristic vertical motion with a frequency of 36 cycles per minute and a very moderate amplitude. Traffic was still crossing the span, when without any warning this motion changed instantly to a frequency of 14 cycles per minute with a single node at the center of the span; but for the first time in its history the two cables were not in step. The motion of the two cables being 90 degrees out of phase with each other a violent twisting motion was imparted to the structure which persisted until its ultimate destruction shortly after 11:00 A.M.

This twisting of the structure was confined to the main span, since the side spans were restrained by check reins installed several hundred feet out in the side spans. But in the main span at times the degree of twist surpassed 90

degrees and the lamp posts at the two quarter points actually crossed at right angles as one sighted along the curb. The acceleration at times appeared to exceed that of gravity and the extreme motion at the edge of the sidewalk was in excess of 28 feet vertically, with the cycle complete in a little over 4 seconds. At all times the motion appeared to be more severe at the west side of the main span, since it was in this region that a number of the lamp posts were torn from their foundations and thrown across the deck and it was at this point that the first failure in the girder and suspenders took place.

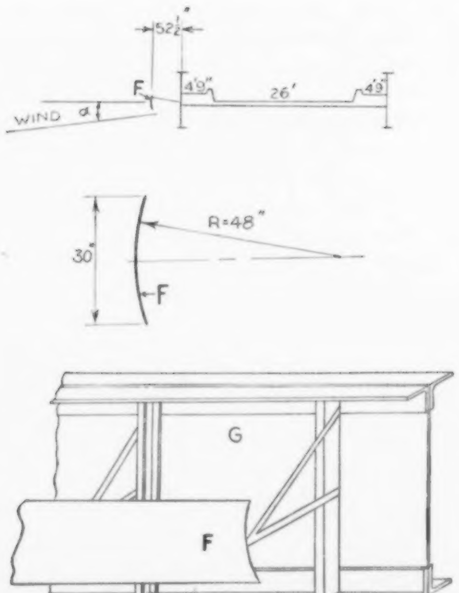
During this motion, which was responsible for the gradual disintegration of the structure, careful observations were taken out to well beyond the quarter point on the main span. Briefly, it appears that the lateral bracing system in the deck failed first; this was followed by a buckling failure in the stiffening girder at about the west quarter point in the main span; presently a series of suspenders on the north side near this same buckling failure let go and the first section of the suspended structure, about 200 feet long, fell into the sound.

The removal of this large amount of weight so agitated the remaining portion of the bridge that it was only a matter of minutes till the whole 2,800 feet comprising the main span had torn loose and plunged into the water. At the same time the side spans sagged 25 or 30 feet and suffered considerable damage but did not tear loose; while the two tower tops were forced so far shoreward that the elastic limit of the steel was exceeded on both tension and compression sides,



TACOMA NARROWS BRIDGE MODEL AT THE UNIVERSITY OF WASHINGTON

PROFESSOR FARQUHARSON DEMONSTRATING THE METHOD USED TO MEASURE CHANGING STRESSES ON THE MODEL.



PROPOSED "FAIRING DEVICE"
Top: CROSS SECTION OF BRIDGE. *Middle:* FAIRING DEVICE. *Bottom:* SIDE VIEW OF SOLID PLATE GIRDER, *G*, AND THE PROPOSED FAIRING DEVICE, *F*.

leaving those members permanently distorted.

The basic source of the trouble with this structure seems to have been in the stiffening girder itself. This is one of two major bridges on which stiffening has been accomplished through solid plate girders instead of the more conventional open truss, and it is of extreme significance that this undulating motion has developed on both of these bridges. Nothing short of complete aerodynamic studies conducted on the many types of suspension bridges now in use could conclusively prove the point, but one might hazard the guess that had the Golden Gate bridge been built with solid plate girder stiffening members the same undulating motion would have occurred.

It seems reasonably certain that had time permitted the installation of the very simple fairing device shown in the accompanying illustration this catastrophic motion would never have developed and the Tacoma Narrows bridge would still stand as the third longest span in the world.

F. B. FARQUHARSON,
Associate Professor,
Civil Engineering
UNIVERSITY OF WASHINGTON

TACOMA NARROWS BRIDGE—STATISTICAL DATA

THE Tacoma Narrows suspension bridge was approved as a PWA project and allotment made June 23, 1938. The original grant was for \$2,700,000 toward an estimated construction cost of \$6,000,000. Two subsequent amendatory applications filed by the applicant, The Washington State Toll Bridge Authority of Olympia, raised the grant to a final figure of \$2,964,150 toward an estimated construction cost of \$6,587,000.

The bridge consisted of a suspension structure having a total length of 5,000 feet, divided by a central span of 2,800 feet and a span on either side of 1,100 feet. With approaches and anchorages, the structure presented an over-all length of 5,539 feet, containing a two-lane concrete roadway 26 feet wide flanked on either side by a 4 foot 9 inch sidewalk. For navigation a minimum vertical clearance of 196 feet was provided. The central span of 2,800 feet was exceeded by only two others—the 3,600 foot central span of the George Washington Bridge in New York City and the 4,200 foot central span of the Golden Gate Bridge at San Francisco. The two main towers, each 425 feet high, marked a major advance in suspension bridge design. They are what is known as "flexible" towers and although rigidly anchored in concrete caissons, the top of the towers could be moved as much as 5 feet in the direction of the longitudinal axis of the bridge in either direction.

Girders, floor beams and stringers for the floor were brought by water from Pennsylvania to the bridge site, assembled on barges into complete sections of roadway and lifted into place by travelers mounted and traveling on the main cables.

Each of the steel towers contains 3,750,000 pounds of structural steel and the cost of each is approximately \$250,000. The two main cables supporting the central span were 17½ inches in diameter and consisted of 6,300 parallel wires and from anchorage to anchorage were 5,772 feet in length.

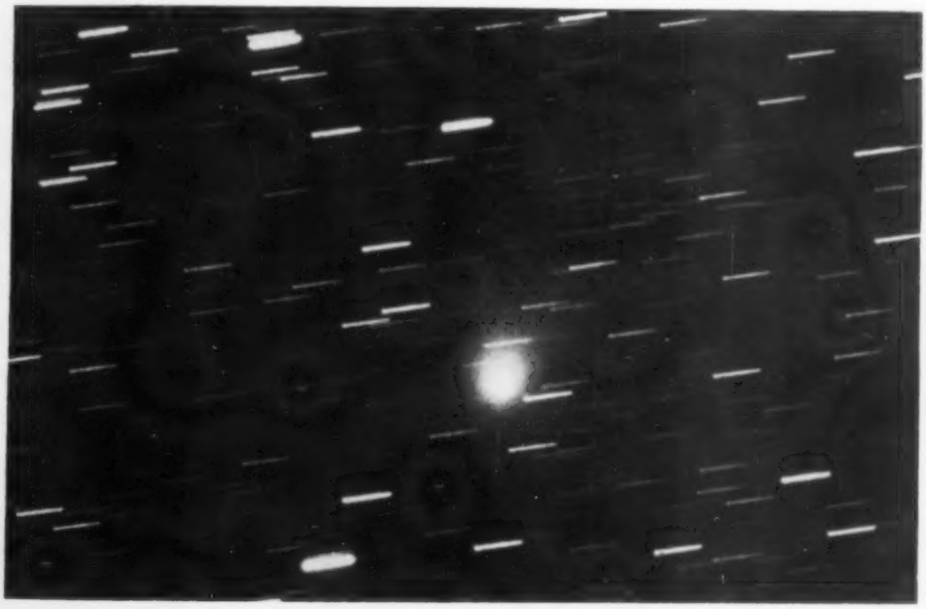
The project was completed in 19 months, a record in bridge construction, and was dedicated and opened to the public on July 1, 1940.

COMETS OF 1940

ALTHOUGH the crop of comets in 1940 has been very mediocre in number, the occurrence of one rare specimen has more than compensated for the scarcity. Comet Cunningham, the third to be discovered in 1940, shows promise of becoming the brightest and most thoroughly observed comet in many years. By the end of this year it should be fairly conspicuous to the naked eye and by the middle of January, 1941, should be very bright but too far south for observation from northern latitudes.

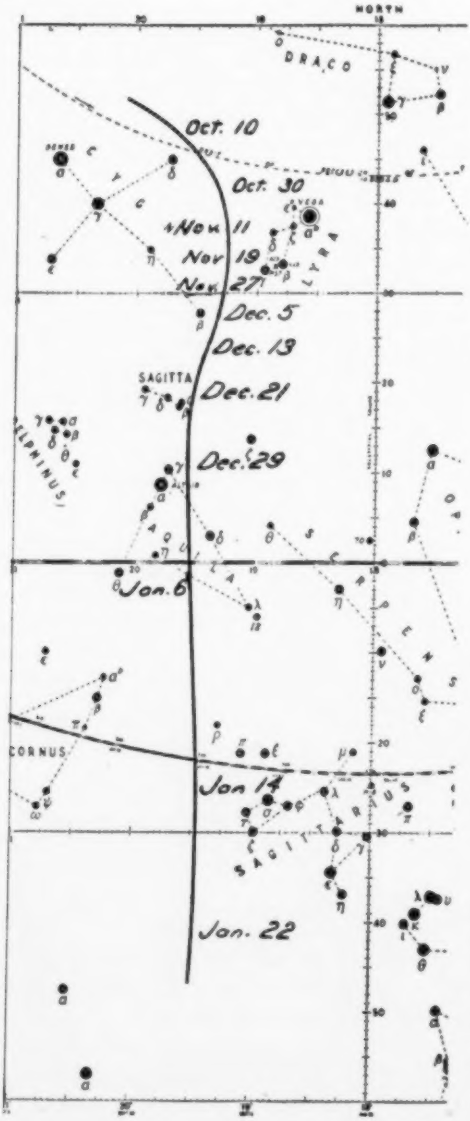
The first eight months of 1940 were distinguished by the discovery of no comets, except for one case in which an object thought at first to be a comet was finally classified as an asteroid. The first confirmed discovery came on September 1, when L. E. Cunningham, of the Harvard Observatory, found comet 1933f in the position predicted for its return by Dr. G. G. Cillié and W. A. Johnson, both at Harvard when the calculations were made. This faint periodic comet is particularly a Harvard possession, because it was originally discovered by the writer in 1933. At this return, its first since it was last observed in January, 1935, by Dr. H. M. Jeffers, of the Lick Observatory, comet 1933f is only six hours off schedule. The error is slightly greater than one part in ten thousand of the period of revolution about the sun. The period is the least certain of the orbital elements. Comet 1933f is chiefly of interest because of the low eccentricity of its orbit, only 0.35.

Two weeks after his premeditated rediscovery of comet 1933f Mr. Cunningham discovered a new comet, 1940c, while searching the Harvard plates. It is 1940c that stands out as the colossus of the 1940 harvest of comets. In Septem-



COMET CUNNINGHAM, SOON TO BE VISIBLE WITH THE UNAIDED EYE

PHOTOGRAPHED OCTOBER 25, 1940, WITH THE 16-INCH HARVARD COLLEGE OBSERVATORY TELESCOPE. SINCE THE TELESCOPE FOLLOWED THE COMET WHICH WAS MOVING WITH RESPECT TO THE STARS, THE STAR IMAGES DRIFTED ON THE PLATE, PRODUCING STREAKS.



PATH OF COMET CUNNINGHAM
IN 1940 AND JANUARY, 1941.

ber it was quite faint (13^m) but was about two and a half times the earth's distance from the sun. At this distance only comets that are intrinsically very large can be observed and they are rarely discovered so far away. Calculations indicate that Comet Cunningham should increase from its discovery brightness by a factor of nearly a million times, as seen from the earth. So far (early November) the predicted increase of nearly a hundred-fold is observed and there is little question that the comet will live up to expectations. Most of the calculated increase arises from the remarkable fashion in which comets brighten as they approach the sun. Instead of obeying an inverse-square law in the distance, they are apt to follow even an inverse-sixth-power law, although no general equation can follow accurately the perverse light variations of a comet.

A recent photograph of comet 1940c (exposed by Mr. Cunningham) is reproduced here. A chart of the predicted path is also shown for the convenience of those who may wish to observe the comet. The solid curve represents the apparent path and the dates show the positions along the path. For those who wish merely to see the comet I suggest that no attempt be made until late in December when the moon has left the evening sky. Comet Cunningham should be easily visible with the naked eye in the early evening after the sky becomes moderately dark. Look west or a little north of west a few degrees above the horizon. In cities where the sky is artificially illuminated the comet may still be difficult to see, but in country areas it should be fairly conspicuous. In early January before the moon has again become bright, the comet should be as conspicuous as the brightest stars, but will have moved farther south. By the middle of January it will be too far south for observation from most of North America.

Another new comet, 1940d, was photographed on the Harvard patrol plates in early August but was not detected until late September, when the present writer was searching the plates of that period. By the time of the actual discovery the comet had moved into the southern sky near the South Pole, but was found by

Dr. Bobone, at Cordoba, Argentine, near the position predicted by Dr. A. D. Maxwell and by the writer. Early in October Dr. J. S. Paraskevopoulos, superintendent of the Harvard Station in Bloemfontein, South Africa, independently discovered the comet on plates taken there. Announcement of the previous discovery had not reached him, presumably because of war conditions.

It is worthy of comment that comet 1940d was discoverable at Harvard only because the European asteroid observers and visual observers were inactive. In early August the comet passed through the center of the asteroid region, near the ecliptic at opposition to the sun. Ordinarily it would have been found and announced immediately before there was a chance of finding it on plates taken with the small patrol cameras. Comet 1940d will not again be observable from the latitude of Cambridge, but is still fairly bright photographically in the south, although several times too faint for the naked eye.

The periods of revolution about the sun for both comets, 1940c and 1940d, are probably too great for either to be observed at a future return by any one living to-day.

The last comet so far reported in 1940 was observed in early October by Okabayasi, a Japanese astronomer near Tokyo. It was then not far from the sun in the sky and already past perihelion. It is now faint, about the twelfth magnitude, and will continue to fade in brightness. The motion about the sun is retrograde, according to orbit calculations by Miss Scott at the University of California and by Dr. A. D. Maxwell and F. J. Wood at the University of Michigan. It is probable, therefore, that the period of revolution about the sun is a great many years.

Besides the general interest and astronomical importance of the bright comet discovered by Cunningham, perhaps the most unusual feature of the four 1940 comets is the fact that they were all discovered within a period of only five weeks.

Fred L. Whipple
Harvard College Observatory

THE ANNUAL EXHIBITION OF THE CARNEGIE INSTITUTION

Beginning on Saturday, December 14, and continuing on Sunday and Monday, the Carnegie Institution of Washington again holds open house for the public in its Administration Building at Sixteenth and P Streets, N. W., Washington, D. C. At this time various departments and laboratories of the institution will have on display exhibits illustrating some of their recent work.

Although a considerable part of the facilities and effort of the institution is at present directed to problems relating to national defense, yet as much as possible of the basic research, upon which the future of science rests, is being continued. In pursuing this course, the Geophysical Laboratory, with the cooperation of the Department of Terrestrial Magnetism, has undertaken the construction of an apparatus to produce extremely high pressures, in the neighborhood of three million pounds per square inch. A pressure of this magnitude corresponds to that found at a depth of 300 miles below the surface of the earth. It thus becomes possible to study in the laboratory the behavior of metals and minerals under such extreme conditions as are found in the earth's interior. One result already obtained with this apparatus is of great interest in the study of terrestrial magnetism, for it has been found that high pressures counteract the tendency of some ferromagnetic substances to lose their magnetism at high temperatures. Accordingly, it is possible that part of the earth's magnetism can be accounted for by the presence in its interior of materials which

APPARATUS FOR EXTREME PRESSURES

retain their magnetic properties in spite of the high temperatures prevailing there. The Geophysical Laboratory will have an exhibit showing some of the applications of this apparatus.

Another interesting exhibit will be that of the Division of Plant Biology, offering paleobotanical evidence indicating large-scale climatic changes in the Pacific Northwest during recent geologic ages. This has resulted in the southward migration of the old forests and their replacement by new types of trees.

One of the most complete records of the plant life of the past 50 million years to be found anywhere is preserved in the fossil deposits of the John Day Basin in Oregon. This record shows a gradual change from the large, heavy leaves of a subtropical forest living in this region during the Eocene period 50 million years ago to the present-day vegetation. Included in this exhibit will be specimens of leaves of the fossil plants from the John Day Basin and leaves from their living relatives now found much farther to the south, arranged to show the slow change of the Oregon forests and their movement southward.

The Department of Genetics will have an exhibit on the gene, the extremely small units, which are the carriers of hereditary characteristics, found in the chromosomes of the cells. The exhibit of this department will show the correlation between the bands found on the chromosomes of the fruit-fly (Drosophila) and the positions of the genes.

There are genetic experiments with the fruit-fly which can be easily performed by students in the high-school laboratory. The department has prepared a booklet describing these experiments and has also arranged to supply the schools with fruit-flies. The exhibit will illustrate this educational work.

At the time of the exhibition there will also be a showing of two other sets of pictures; one a diversified series of water colors portraying the Aztec god Xipe Totec, the second a series of photographs of active volcanos, including Stromboli, Vesuvius, Etna and Pelée. During the past summer this latter series was shown at the World's Fair in New York.

The Mount Wilson Observatory will have an exhibit consisting of photographs and charts illustrating new developments in the study of supernovae. These are the stars which, for some reason we do not yet understand, suddenly "blow up." Their size and their light output increase tremendously in a very short time, then they slowly fade away, until they are at last lost to our view in the depths of space.

On the evening of December 10, Dr. Edwin Hubble of the observatory will give a public lecture on these strange stars. In addition, as has been the custom in the past, short lectures based on the material of the exhibits will be given during the course of the annual exhibition.

G. B. H.

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J. McKEEN CATTELL, F. R. MOULTON AND WARE CATTELL

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NEW BOOKS OF SCIENTIFIC INTEREST

An Introduction to the Kinetic Theory of Gases. J. JEANS. xvii + 311 pp. $3.50. 1940. Macmillan.

This book attempts to provide such knowledge of the Kinetic Theory as is required by the serious student of physics and physical chemistry, and also to give the mathematical student the equipment necessary for the study of special monographs.

Foundations of Modern Physics. T. B. BROWN. Illustrated. xviii + 333 pp. $3.25. 1940. Wiley.

An outgrowth of a course in modern physics at George Washington University, the emphasis of this book is laid upon experimental aspects of modern physics and upon the evidence which these experiments give in support of new theories.

College Physics. J. A. ELDRIDGE. 2nd Ed. Illustrated. lv + 702 pp. $3.75. 1940. Wiley.

The author has designed this text-book to interest non-science majors as well as those specializing in physics. Emphasis is laid upon problems and materials which are familiar to the students in their everyday life.

Television Today and Tomorrow. S. A. MOSELEY and H. J. BARTON-CHAPPLE. 5th Ed. Illustrated. viii + 179 pp. $3.00. 1940. Pitman.

This book gives information on the apparatus, methods and general principles employed in television. It tells how television was developed and includes accounts of work in ultra-short wave television, special television methods, and the latest "televisors."

Studies of Cenozoic Vertebrates and Stratigraphy of Western North America. P. C. HENSHAW, R. W. WILSON, H. HOWARD, A. H. MILLER, J. F. DOUGHERTY, R. H. JAHNS. ix + 199 pp. Illustrated. Paper bound. 1940. Carnegie Institution.

This publication contains nine reports of discoveries of fossils in the western United States by members of the Carnegie Institution. The specimens represent rodents, lagomorphs, camels and other mammals.

Contributions to Embryology. ix + 451 pp. Illustrated. Paper bound. 1940. Carnegie Institution.

A series of nine papers published under the auspices of the Carnegie Institution of Washington. Experimental studies on the development of embryos in man, the chimpanzee, the rhesus monkey, the rabbit and the alligator are reported.

Essentials of Zoology. G. E. POTTER. Illustrated. xxvii + 526 pp. 1940. Mosby.

This college text seeks to present the fundamentals which every zoology student should know, whether or not he plans to take more advanced courses in the field. The arrangement of topics is flexible and may be adjusted by the teacher to his needs.

Man and the Living World. E. E. STANFORD. Illustrated. xxxv + 916 pp. $3.50. October, 1940. Macmillan.

A college text for a "survey course" in biology. Minimizing somewhat morphological and physiological matters, it throws its emphasis on man—the human body, human interests in living things, and the organizational patterns of the world in which man lives.

Developmental Anatomy. L. B. AREY. Illustrated. xix + 612 pp. $6.75. 1940. Saunders.

This textbook and laboratory manual of embryology is divided into three parts: General Development, Organogenesis, and the Laboratory Manual. The book treats mainly the human embryo, but also includes discussions of fishes, birds, reptiles, pigs and chicks.

Principles of Genetics. E. G. WHITE. Illustrated. xxi + 352 pp. 1940. Mosby.

In writing this text, the author has tried to keep in mind the interests of the average student in the wider aspects of genetics and its practical applications. An effort has been made to stimulate thought and encourage further investigations.

Multiple Human Births. H. H. NEWMAN. Illustrated. xv + 214 pp. $2.50. 1940. Doubleday, Doran.

This first book in the American Association for the Advancement of Science Series answers for the layman such questions as: How frequently do twins occur, do they run in families, are they as intelligent as other children, do they remain similar when separated from childhood?

Adaptive Coloration in Animals. H. B. COTT. Illustrated. 508 pp. $8.50. 1940. Oxford.

This book deals with the nature and meaning of coloration in the animal world. The first part deals with concealment; the second with advertisement, whether for warning or alluring; the third with disguise—about animals that imitate other animals or their own environment.

Essays in Historical Anthropology of North America. Illustrated. xiii + 600 pp. $2.00. 1940. Smithsonian Institution.

Published in honor of John R. Swanton, this volume contains articles by members of the Smithsonian Institution staff summarizing knowledge of various aspects of the history of the North American Indian. A bibliography and a sketch of the work of Dr. Swanton are included.

John and William Bartram. E. EARNEST. xvi + 187 pp. $2.00. 1940. University of Pennsylvania.

This is the biography of John and William Bartram, father and son, who were early American botanists. Not limited to one field, William Bartram's accounts and discriptions helped to shape the philosophy of nature which was soon to develop in English literature.

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